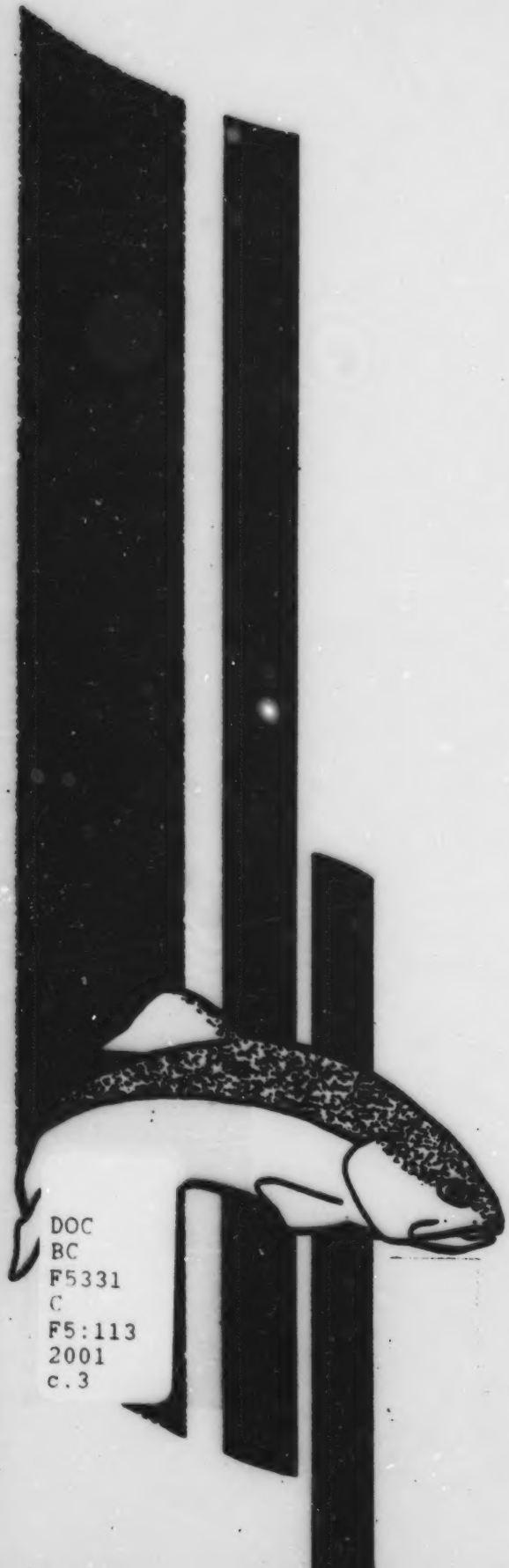

Freshwater habitat requirements of anadromous cutthroat trout and implications for forestry impacts

by

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Abstract

This report evaluates the freshwater habitat requirements of juvenile anadromous cutthroat trout based on independent field research and published studies, and evaluates the effectiveness of the B.C. Forest Practices Code riparian regulations in protecting sea-run cutthroat trout habitat. Until the early part of the 1990s, most streams in coastal British Columbia were clearcut to the streambank, resulting in the cessation of inputs of Large Woody Debris (LWD) from riparian zones. LWD from riparian (streamside) trees falling into the stream channel is the major pool-forming mechanism in small and medium-sized coastal streams, where pools and the complex structure associated with LWD provide critical habitat for juvenile salmonids. Channel structure and juvenile rearing capacity in many south coastal streams impacted by logging will continue to decline in the foreseeable future (over the next 50-100 years) until riparian forest matures sufficiently for larger trees to begin dying and entering the stream channel in significant numbers. The intent of riparian regulations in the B.C. Forest Practices Code is to prevent further damage to stream habitats, and to ensure that ecosystem functions provided by intact riparian zones are not compromised by resource extraction or other landuses.

Research described in this report highlights several specific habitat requirements of cutthroat trout that have important implications for habitat management. First, at the drainage basin or landscape scale, juvenile anadromous cutthroat trout occur at their highest densities in small (< 5 m channel width) low gradient streams or tributaries to larger rivers (see Chapter 1). Small streams that are permanently wetted are used as summer low-flow rearing habitat, and small seasonally wet streams are used as overwintering habitat. Small streams also account for the majority of useable habitat for juvenile cutthroat trout in coastal watersheds (Chapter 2). Second, at the instream habitat scale, pools are critical habitat for growth of larger cutthroat trout (Chapter 3), and most pools (>50%) are formed by scour associated with LWD unless the channel is steeper gradient and boulder or bedrock controlled.

An evaluation of the B.C. Forest Practices Code riparian regulations and operational procedures with respect to protection of cutthroat habitat identifies several

significant shortcomings. Independent audits (Sierra Legal Defence Fund 1997, Forest Practices Board 1998) have found that systematic misclassification of streams is the main operational problem reducing the effectiveness of riparian protection. A large proportion of small (S3 or S4) streams in cutblocks were found to be unidentified during operational planning, or misclassified so that they received a much lower level of riparian protection than required under the code. Fifty-one percent of S3 streams were misclassified as S4 in one audit (Forest Practices Board 1998), resulting in the mandatory 20 m riparian reserve being clearcut to the stream bank on 35% of the audited S3 streams. This is particularly damaging to anadromous cutthroat trout habitat because juvenile trout rear at their highest densities in S3 and S4 streams, and clearcutting will reduce future recruitment of LWD inputs to the stream channel, likely resulting in future decreased pool frequency and lowered habitat capacity.

Although the forest practices code does provide protection for many aspects of riparian ecosystem function, it has technical shortcomings that will contribute to cumulative negative impacts on anadromous cutthroat trout rearing habitat. These include i) reduced LWD inputs to S3 streams because of inadequate riparian buffer width, ii) degraded S4 stream channel structure from depletion of LWD inputs due to streambank clearcutting and inappropriate cross-stream yarding, and iii) potential increases in sediment inputs and reduction of LWD transport to downstream reaches from fishless S5 and S6 streams. Although the 1998 Forest Practices Board audit of riparian management in coastal BC found reasonably good compliance with FPC riparian management regulations (correct classification of streams excepted), incidents of poor compliance and enforcement have been found in other regions (Forest Practices Board 1999), indicating a need for enhanced monitoring and enforcement of code regulations. Ensuring effective protection of stream habitat requires the development of formal monitoring programs to ensure compliance and evaluate the effectiveness of different riparian management practices, including regular monitoring of treated sites to evaluate the long-term effects of different riparian prescriptions.

Information gaps with respect to forestry impacts on stream habitat include the relative contribution of small streams to total stream habitat in different biogeoclimatic zones, and the importance of fishless streams. The ecological role of small fishless S5 and S6 streams in terms of invertebrate production and sediment and organic matter

storage and export to downstream fishbearing reaches remains unclear. The cumulative effects of clearcutting smaller fishless streams on fish-food production and transport to downstream fish-bearing reaches is largely undocumented, and requires further assessment.

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Introduction

Coastal cutthroat trout (*Oncorhynchus clarki clarki*) are a salmonid endemic to the west coast of North America with their range centered in British Columbia (Scott and Crossman 1973). Cutthroat trout display a wide diversity of life-history strategies; like steelhead (sea-run rainbow trout; *Oncorhynchus mykiss*), many populations are anadromous, with juveniles migrating to the ocean to mature as adults in near-shore estuarine areas. Unlike steelhead, which tend to spawn and rear in cobble-boulder streams, sea-run cutthroat trout typically spawn and rear in very small low-gradient streams or tributaries to larger rivers (Hartman and Gill 1968; DeLeuuw and Stuart 1981). Resident and sea-run cutthroat trout are ubiquitous along the coast, and populations will occur in virtually any coastal stream with permanent flow and adequate spawning and rearing habitat (J.D. McPhail, Dept. of Zoology, University of British Columbia, personal communication). As with all coastal salmonids, anadromous populations are confined to waterbodies with no migration barriers to the ocean, including streams with anadromous reaches as short as 30m (J.S. Rosenfeld, personal observation). Although cutthroat trout do not support a commercial fishery, they are a prized sport fish and their genetically diverse population structure (Williams et al. 1997, Wenberg et al. 1998) contributes substantially to the biodiversity of British Columbia's fish fauna.

Urbanization, agriculture, and forestry in coastal areas tend to focus on valley bottoms, where the small low-gradient streams used by cutthroat trout are most abundant, making them highly vulnerable to a suite of negative impacts associated with different land-use practices (Reeves et al. 1997). Riparian management regulations, both urban and forestry-related, offer relatively poor protection to the smallest streams that tend to be favored by cutthroat trout. Consequently many populations of cutthroat trout have been extirpated (Slaney et al. 1996), others are in decline (Johnson et al. 1999), and the status of many is unknown. Deterioration of freshwater habitat is not a problem unique to cutthroat trout, since juvenile trout frequently occur with other species, most commonly juvenile coho salmon (coho salmon co-occurred at 84% of cutthroat stream sites less than 10m channel width in one recent survey; Rosenfeld et al. 2000). However,

management of anadromous cutthroat trout is complicated by a relatively poor understanding of their biology and habitat requirements (Hall 1997).

Determining the suite of conditions that define the habitat "requirements" of a species is a primary goal of aquatic research and management. Broadly speaking, requirements are features of the environment that are necessary for the persistence of individuals or populations. This information is critical for managing the habitat of a species or for predicting how habitat change will effect populations. When faced with conflicting land uses in an area (e.g. wildlife protection versus timber harvest or urban development), it is necessary to identify the subset of critical habitats or features upon which the persistence of a species or population is dependent. Without this knowledge, managing habitat either defaults to educated guesswork, or a conservative strategy of protecting everything. The first approach is not acceptable because it is likely to fail, and the second approach often has economic and social consequences that are difficult to justify. Clearly defined habitat requirements are the only credible basis for predicting the outcome of different management actions.

This management report describes the results of a 3-year study intended to define the freshwater habitat associations and requirements of juvenile cutthroat trout. Specific research objectives were i) to define the principal factors that determine the presence and abundance of anadromous cutthroat trout in coastal streams, with a specific focus on the role of large woody debris (LWD; Chapter 1), ii) to assess the distribution of cutthroat trout habitat at the landscape scale and measure the relative contribution of small streams to total available habitat (Chapter 2), and iii) to determine the effect of channel structure on juvenile cutthroat growth and distribution (Chapter 3). Management objectives are to use this information on habitat requirements to evaluate potential forestry impacts on anadromous cutthroat trout, and to evaluate the ability of current B.C. Forest Practices Code Regulations to adequately protect cutthroat trout habitat (Chapter 4).

CHAPTER 1: Habitat Factors Affecting Juvenile Abundance And Distribution

ABSTRACT

The distribution, abundance, and habitat associations of juvenile coastal cutthroat trout (*Oncorhynchus clarki clarki*) and coho salmon (*Oncorhynchus kisutch*) were evaluated using survey data from 119 sites in coastal British Columbia. Since coho juveniles co-occurred with cutthroat at most sites, it was assumed that most cutthroat were anadromous, although some unknown proportion of resident cutthroat were likely present. Both cutthroat and coho occurred at their highest densities in very small streams (less than 5m bankfull channel width), and bankfull channel width was the single best predictor of cutthroat presence ($p=0.0001$) and density ($R^2=0.55$). Within a channel, densities of coho and larger (yearling and older) cutthroat parr were highest in pools, while densities of young-of-the-year (yoy) cutthroat were significantly lower in pools and highest in shallower habitats. Abundance of larger cutthroat parr and pool habitat were positively correlated with large woody debris (LWD) within a subset of intermediate gradient gravel-cobble streams, where pools appear to be limiting larger cutthroat parr abundance. More than 50% of pools were formed by scour associated with LWD in streams ranging from 1.2-11 m bankfull channel width, and pools formed by LWD scour were on average 10% deeper than pools formed by other mechanisms. Disproportionate use of small streams by cutthroat indicates that protection of small stream habitat is important for long-term conservation of cutthroat populations.

INTRODUCTION

This chapter describes the factors influencing the presence and abundance of cutthroat trout and the role of LWD in channel structure, based on surveys carried out during June-September 1997 and 1998 at 119 sites in coastal British Columbia (Rosenfeld et al. 2000). We also include a comparative analysis of coho distribution, which occurred with cutthroat at most sites. The specific objectives of this section are to define:

i) habitat factors correlated with juvenile cutthroat abundance

ii) longitudinal changes in density of juvenile cutthroat trout and coho salmon

iii) instream habitat associations of different size-classes of juvenile cutthroat trout (yoy, < 80 mm, 80-110 mm, and larger parr >110mm), and

iv) the influence of LWD on channel structure of small coastal streams.

METHODS

Study design

Fish and habitat data was collected using a combination of intensive sampling at new sites (n=33) and the use of a larger independent data base (n=86 sites) collected during stock assessment surveys by the British Columbia Ministry of Fisheries (Burt and Horchik 1998). Sites were located in three separate coastal regions: the west coast of Vancouver Island within a 30 km radius of the town of Tofino, the Sechelt Peninsula on the southern mainland, and the Bella Coola watershed on the central coast of British Columbia. Dispersal of sampling regions across the province ensured that inferences from the study are broadly applicable to a significant portion of the range of cutthroat trout.

Location of sites sampled during provincial stock assessment inventories were based primarily on access and the need to sample representative streams and reaches for stock assessment purposes. Because inventory sites included primarily medium to large channels (up to 143 m bankfull channel width), there is an information gap with respect to cutthroat habitat use in smaller streams (less than 5m bankfull width). To generate a more complete data set including a full range of channel widths, sites selected for more intensive sampling consisted of a subset of smaller streams (1.2-11.2 m channel width). To ensure that selected sites were representative of the range of conditions available to cutthroat trout, streams were chosen to encompass a broad range of channel and basin gradients (0.5 – 10.4 % and 1 - 66%, respectively) associated with high and low gradient topographies. Within these constraints, sites were selected within each region based primarily on logistics and ease of road or boat access. Sites were in predominantly forested drainages, and had variable land-use histories ranging from recently logged to old growth.

Intensive study sites were sampled at summer base flow during June-September 1997 and 1998. Sites consisted of 4-20 contiguous channel (habitat) units (average of 9) that were visually representative of the average conditions in the stream reach. In smaller streams the limited area of individual channel units generally required electrofishing of more channel units to ensure capture of sufficient fish for a reliable depletion estimate. The area electroshocked at a site ranged from 21-469 m^2 (average of 94 m^2) depending on channel size. In some instances the area electroshocked

represented a significant proportion of available habitat (21 m^2 at the smallest site represented 52% of the available habitat in a stream with a very short anadromous reach).

The 33 intensively sampled sites were distributed among 23 independent streams draining directly into the ocean. Fourteen sites were located on separate tributaries of four of the larger streams. Stock assessment sites within the Bella Coola watershed were dispersed throughout several hundred kilometers of mainstem and tributary habitat (Burt and Horchik 1998).

In order to control for differences in stream characteristics (channel size, water chemistry and logging history) that might confound detection of habitat associations in a broader regression analysis, paired sites that differed only in channel complexity (high or low habitat structure) were sampled within a subset of five gravel-cobble pool-riffle streams near Sechelt. One site in each pair within a stream was characterized by a high abundance of LWD, whereas the other site in the pair had little or no LWD present.

Data collection

Fish were collected by triple pass electroshocking of stop-netted sections using a backpack electrofisher. Shocked areas were left undisturbed for at least 45 minutes between passes, with the same shocking time (± 10%) and operator during each pass. Stop-netted sections were chosen to be representative of the average channel characteristics of the stream reach. To document associations of fish with discrete channel unit types, individual (usually contiguous) channel units were isolated using multiple stop-nets at 23 of the 33 intensively sampled sites. Fish were measured to the nearest mm and weighted to the nearest 0.1 g after each pass. Fish collection for stock assessment purposes was similar in the Bella Coola drainage, but used only double pass depletion of stop-netted sections (Burt and Horchik 1998); nets were set up to enclose a section of river margin at larger river sites in the Bella Coola when it was impossible to stop-net the entire river.

Canopy closure was visually estimated at each site and conductivity (an index of site productivity) was measured to the nearest µSiemen with a hand-held meter (Cole-Parmer TDStestr-30). Basin gradient (basin elevation divided by valley length above a site) and percent valley flat (proportion of a basin less than 7% gradient) were digitized

from 1:20,000 and 1:50,000 topographic maps. The diameter (b-axis) of the largest particle moved by flowing water was estimated at each site as an index of stream power and channel condition (Province of British Columbia 1996), and average bankfull channel width (henceforth channel width) was identified based on the limit of permanently rooted vegetation.

Each channel unit in the electroshocked section was classified as a pool (0% gradient, low current velocity, deep), glide (0-1% gradient, slow current velocity, minimal water surface turbulence), run (high current velocity, turbulent flow), riffle (1-3% gradient, high current velocity, water surface broken by protruding substrata, shallow), or cascade (>3% gradient, high current velocity, water surface broken by larger substrate particles) as described in Johnston and Slaney (1996) and Moore et al. (1997). Substrate composition (fines < 2mm, gravel 2-64 mm, cobble 64-250 mm, boulder 250-4000 mm, and bedrock> 4000 mm) was visually estimated in each channel unit. If the channel unit was a pool, pool-forming mechanism was recorded as either boulder scour, LWD scour, bank scour, or free-form (Montgomery et al. 1995). Size and abundance of LWD (wood greater than 15 cm in diameter and 1 m in length) was measured at the intensively sampled sites using the methodology outlined in Moore et al. (1997). In order to obtain a larger sample size of pools than was present in the electroshocked channel units, LWD and pool-forming mechanism were characterized over a longer distance of 10-20 bankfull channel widths that included the electroshocked area. Site gradient was also estimated to the nearest 0.5% over the longer distance using a Sunnto clinometer, and was representative of the section of stream from which fish were collected. Since site gradients ranged from 0.5-10%, a combined user and instrumental error of $\pm$ 0.5% was considered sufficient to capture relationships between fish abundance and channel structure.

Data analysis

Estimation of population size

Population size at each site was estimated from removal data using the Schnute maximum likelihood procedure (Schnute 1983) adapted to a three-pass depletion (T. Johnston, B.C. Ministry of Fisheries, unpublished data). Time constraints prevented a third pass at 2 of the intensively sampled sites, where populations were estimated using a two-pass removal estimate (Seber 1982). Fish density from double-pass depletions in

the Bella Coola were also estimated as two-catch removals (Burt and Horchik 1998, Seber 1982). Populations of fish in individual channel units were also estimated as 3-pass depletions (Seber 1982).

Correlation of habitat factors with fish presence and abundance

All data analyses were performed using PC SAS (SAS Institute 1989). The presence/absence of cutthroat and coho at a site were modeled as a function of bankfull channel width using logistic regression with a combined data set of sites from Vancouver Island, Sechelt, and Bella Coola (n=119).

To determine which habitat factors influenced juvenile salmonid abundance, total cutthroat and coho abundance at the subset of intensively sampled sites (n=33 for cutthroat, n=31 for coho) were modeled as a function of bankfull channel width, dominant substrate class, percent pool, b-axis of the largest particle moved by flowing water, percent valley flat, reach gradient, canopy cover, conductivity, and either coho or cutthroat density. Factors which were not significant at $p = 0.05$ were dropped from the analysis. Cutthroat and coho densities and bankfull channel width were log-transformed $(x + 0.1)$ and percent pool was arcsine square-root transformed to meet assumptions of normality and equal variance. The constant a in log (x+a) transformation was selected based on the criteria of maximizing normality of regression residuals (Berry 1987), which was assessed using the Shapiro-Wilke statistic (SAS Institute 1989) and a frequency histogram of residuals. The assumption of homogeneity of variance in multiple regression was evaluated by testing for a significant correlation between the absolute value of residuals and predicted values. All final regressions met assumptions of normality and homogeneity of variance at $p=0.05$. To control for non-independence of sites in the same region or watershed (Dunham and Vinyard 1997), region (Sechelt, Vancouver Island, and Bella Coola) and drainage basin were included as class variables in regression analysis (i.e. sites were treated as a block when tributary streams shared the same outlet to the ocean). Drainage basin and region effects were dropped from regression analysis when not significant ($p=0.05$).

Juveniles of anadromous cutthroat trout rear in freshwater for up to four years, and consequently span a broad size range (24-201 mm in this study). To assess whether cutthroat habitat associations differ with size, juveniles were divided into three size-

classes for analysis (small, < 80 mm; medium, 80-110 mm; and large > 110 mm) which roughly correspond to 0+, smaller 1+, and larger 1-2+ or older year classes of fish. Results of regressions are presented for total cutthroat and coho abundance, and then for small and large cutthroat separately. To minimize redundancy, results are not presented for the intermediate size-class. Coho juveniles were analyzed as a single size-class, since 96% were less than 80 mm in length (average length 60 mm $\pm$ 12 mm SD).

Longitudinal trends in fish abundance

Longitudinal changes in fish density with increasing stream size were modeled as power functions of channel width, by backtransforming a regression of log fish density on log bankfull channel width (n=119). To adjust for the inherent bias in backtransformation of logged relationships, a correction factor for scaling backtransformed logged values to arithmetic means was calculated as $CF = e^{(MSE/2)*2.303}$ (Sprugel 1983; Baskerville 1971). Cutthroat and coho densities were log (x + 0.002) and (x + 0.008) transformed, respectively, to meet assumptions of normality and equal variance. It was necessary to drop one outlier data point from the cutthroat regression to normalize variance of residuals. Region and drainage basin were treated as class variables in regression as described in the preceding section.

Longitudinal changes in cutthroat and coho abundance along a downstream continuum were expressed as both changes in density per square meter of wetted stream area, and as number of fish per linear meter of stream (the product of density by wetted width). Since cutthroat and coho juveniles are typically associated with channel margins and are rarely found in the deeper faster-flowing center channel of larger rivers (Hartman and Gill 1968), we plotted downstream trends in abundance assuming that the maximum available rearing habitat was either 10 or 20 m wetted width (a 5 or 10 m marginal band along each channel edge) at larger stream sites. We examined longitudinal changes in cutthroat density as a function of channel width rather than wetted width because i) wetted width (and therefore fish density) fluctuates depending on rainfall while channel width is constant, and ii) riparian regulations are specific to different channel width classes, so that evaluating the effectiveness of habitat protection is facilitated by expressing fish abundance in the same units. Although the exact relationship between wetted width and channel width for any given stream will vary depending on regional climate, local hydrology, geomorphology, and groundwater

inputs, there was a strong overall correlation between channel and low-flow wetted widths (R^2=0.96, n=119) despite local and regional effects.

Habitat associations within the stream channel

Selective use of different hydraulic habitats was evaluated as differences in density between channel unit types (n=186 channel units: 81 pools, 61 riffles, 36 glides, 6 runs, and 2 cascades) for the subset of 23 streams where individual channel units were stop-netted. Differences in density of fish between pool, glide, run, and riffle habitats was evaluated using a split-plot ANOVA with sites as blocks (n=23), habitats as plots (n=4), and size-classes (small, medium and large) as sub-plots. Treating size-classes as subplots is equivalent to a repeated measures ANOVA that corrects for the lack of independence of densities of small, medium, and large fish that were collected from the same channel unit (Snedecor and Cochran 1989). Only pool, glide, run, and riffle channel unit types were included in the analyses, since there were too few cascades to apply meaningful statistics.

Effect of LWD on cutthroat abundance

The relationship between cutthroat density and variation in LWD (habitat complexity) within a stream was evaluated by ANCOVA of data from paired sites for small and large size-classes separately. Sites (n=5) were treated as blocks, and percent pool and LWD abundance (continuous metrics of channel complexity) were treated as covariates.

RESULTS

Correlation of habitat factors with fish presence and abundance

Presence of cutthroat trout at a site was significantly predicted (p=0.0001, n=119) as a function of channel bankfull width using logistic regression. The probability function

$$P = e^{(-0.148\,bfw + 3.22)} / (1 + e^{(-0.148 + 3.22)})$$

had a reclassification success of 95% for fish presence, 67% for fish absence, and predicts the presence of anadromous cutthroat trout juveniles in 90% of streams that are less than 7 m bankfull width. Cutthroat trout juveniles were consistently absent from larger river sites (Fig. 1a). No significant logistic regression could be generated for the presence/absence of coho salmon juveniles (p=0.82, n=120), which were present across a broad range of channel widths (1.2 - 142 m; Fig. 1b).

Roughly half of the variance in cutthroat abundance among intensively sampled sites (n=33) was accounted for by instream habitat features (Table 1). Total cutthroat density and density of small cutthroat were negatively related to channel width and percent pool in the sampled reach. Cutthroat densities were also significantly higher when gravel was the dominant substrate class, and lowest when the dominant substrate class was boulder (Fig. 2). Total and small cutthroat densities were positively related to the b-axis of the largest particle moved by flowing water. Density of larger cutthroat was also highest in channels with gravel as the dominant substrate, but was not significantly related to bankfull width, and was negatively related to percent valley A much smaller proportion of the variance in coho abundance was correlated with instream habitat features, although coho density was significantly negatively related to both channel width and site gradient (Table 1). Conductivity, canopy cover, and the density of either coho or cutthroat trout were not significant determinants of cutthroat or coho abundance in the intensively sampled data set (n=33), although there was a weak but significant positive correlation between cutthroat and coho density (R^2=0.27, p=0.003) across the combined data set (n=119).

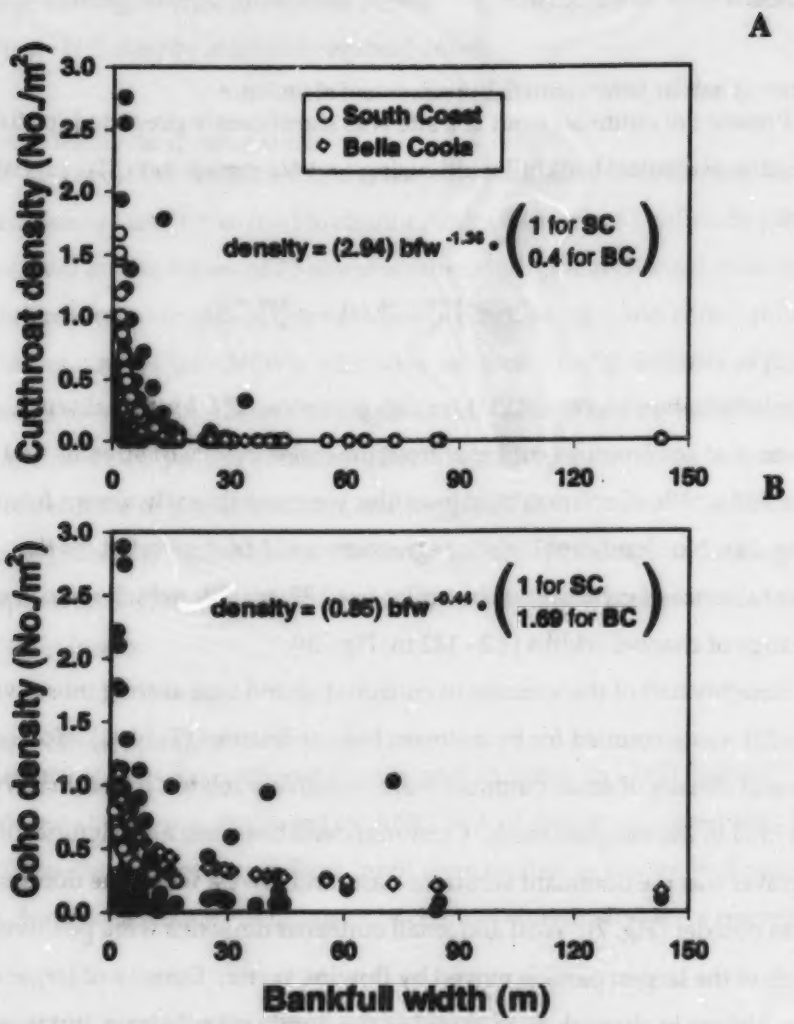


Figure 1. Relationship between fish density and bankfull channel width for cutthroat (A; all age classes combined) and coho (B). Filled circles represent observed densities, open circles (South Coast region) and diamonds (Bella Coola region) represent predicted values based on a back-transformed power function (see Methods and Results section for explanation).

Longitudinal trends in fish abundance

Density of cutthroat trout was significantly related to bankfull width ($R^2 = 0.55$, $p = 0.0001$, $n = 119$ for a log-log relationship), and there was also a significant regional effect on cutthroat density, with higher density in south coast streams (Sechelt and Vancouver Island combined) than in the central coast (Bella Coola; Fig. 3a). There was no significant effect of drainage basin on cutthroat density ($p=0.75$), indicating that variation in cutthroat abundance

Parameters		Regression coefficient	P	Model R^2
Total cutthroat density[a]				
Bankfull width[b]		-0.92	0.004**	0.55
Percent pool[c]		-0.56	0.034*	
b-axis		0.030	0.016*	
Substrate	boulder	-0.86	0.009**	
	cobble	-0.59		
	fines	-0.17		
	gravel	0		
Small cutthroat density[a]				
Bankfull width[b]		-0.89	0.009**	0.53
Percent pool[c]		-0.56	0.045*	
b-axis		0.029	0.030*	
Substrate	boulder	-0.78	0.010*	
	cobble	-0.65		
	fines	-0.19		
	gravel	0		
Large cutthroat density[a]				
Intercept		-0.89	0.0001**	0.40
Percent valley flat[a]		-0.21	0.024**	
Substrate	boulder	-0.28	0.023*	
	cobble	-0.10		
	fines	-0.02		
	gravel	0		
Coho density[a]				
Bankfull width[b]		-0.51	0.044*	0.27
Reach gradient		-0.064	0.010*	

[a] LOG_{10} (x + 0.1) transformed
[b] LOG_{10} (x) transformed
[c] arcsine(square root) transformed

Table 1. Parameters for regressions of coho, small cutthroat (< 80 mm), large cutthroat (> 110mm), and total cutthroat density as a function of habitat variables. Intercepts are only included when significant. Probabilities are for Type 3 sums of squares with the influence of all other factors removed.

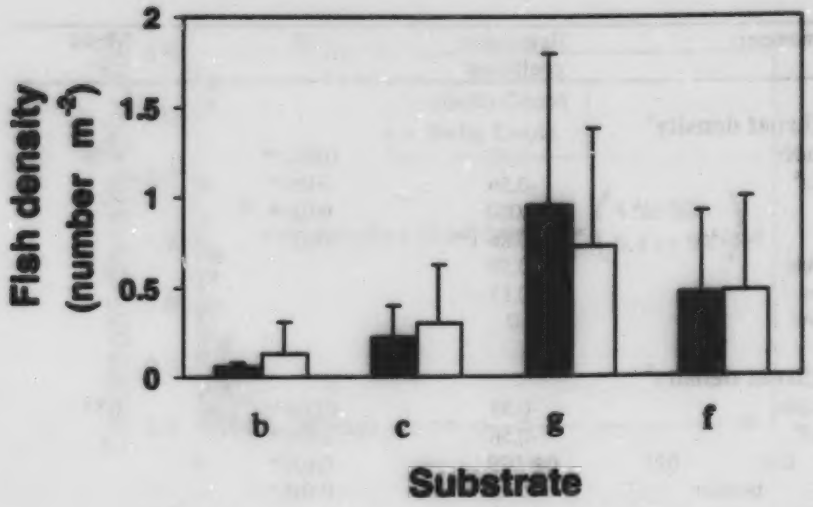


Figure 2. Fish density at sites with different dominant substrate classes (b = boulder, c = cobble, g = gravel, f = fines) for juvenile cutthroat trout (filled bars) and coho salmon (open bars).

between sites within a drainage was much larger than variation between drainages. Cutthroat density was generally highest in the smallest streams (Fig. 3a), as illustrated by backtransforming the log-log relationship (log density = 0.25 -1.36(log bfw) + (0 for S.W. Coast, -0.401 for Bella Coola) to the corresponding power function

$$\text{density} = 1.65 \cdot 1.78 \cdot \text{bfw}^{-1.36 \cdot (1 \text{ for S.W. Coast, } 0.40 \text{ for Bella Coola})}$$

where 1.65 is the correction factor. There was a significant relationship ($R^2 = 0.22$, $p = 0.0001$, $n = 101$; log density = -0.13 - 0.44(log bfw) + (0 for S.W. Coast, 0.23 for Bella Coola)) between coho density and channel width for sites with coho (Fig. 3b); however, the relationship was much weaker ($R^2 = 0.07$, $p = 0.004$, $n = 120$) when sites without coho were included in the analysis, since sites without coho occurred across a broad range of channel sizes, greatly increasing variance in coho abundance. In contrast, the regression of cutthroat trout on channel width was strengthened by the inclusion of sites without cutthroat, which were consistently larger channels. There was also a strong regional effect on coho abundance, with higher coho densities on the central coast (Bella Coola; $F_{1,88} = 8.4$, $p = 0.005$) than on the south coast (Sechelt and Vancouver Island).

The rate of decline in fish density with increasing channel width was much faster for cutthroat than for coho, largely due to the presence of coho at larger river sites, sometimes at higher densities. Consequently, predicted coho densities

$$\text{density} = 1.16 \cdot 0.73 \cdot \text{bfw}^{-0.44 \cdot (1 \text{ for S.W. Coast, } 3.69 \text{ for Bella Coola})}$$

declined much more slowly with increasing channel size. As a consequence of the faster

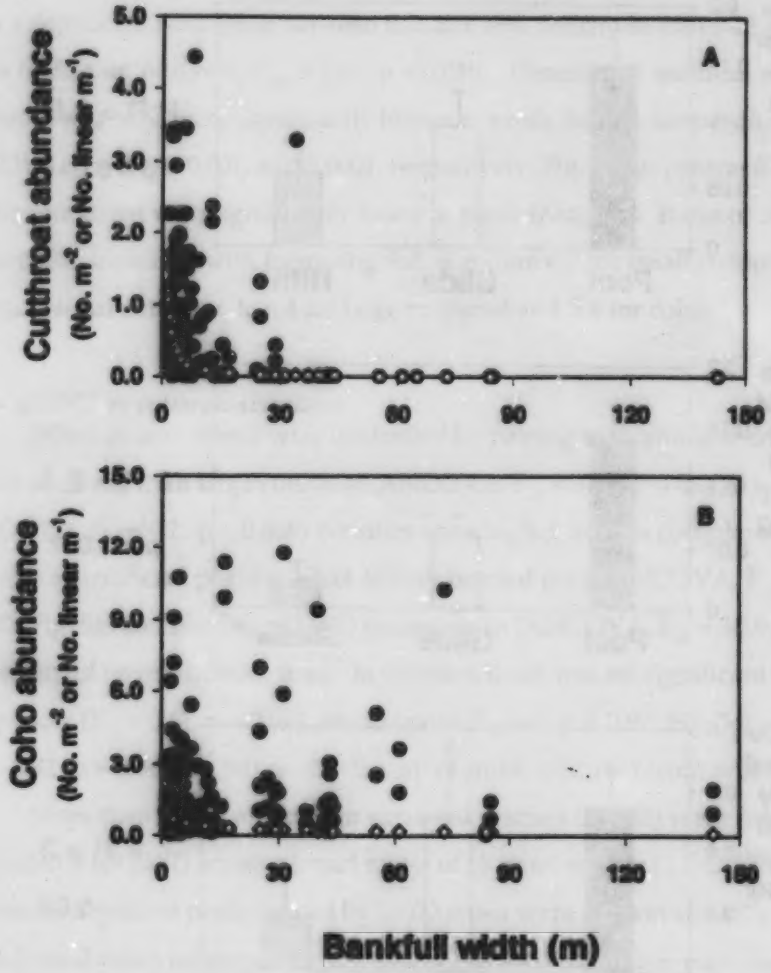


Figure 3. Relationship between predicted fish densities (open circles, average for South Coast and Bella Coola regions), and fish abundance per linear meter of stream channel for juvenile cutthroat trout (A) and coho salmon (B; note difference in vertical scale). Black filled circles represent estimated abundance per linear meter assuming a maximum 5 m of marginal habitat available to juvenile salmonids on either stream bank, shaded circles represent 10 m margins. Two outlier points are off scale on the upper panel.

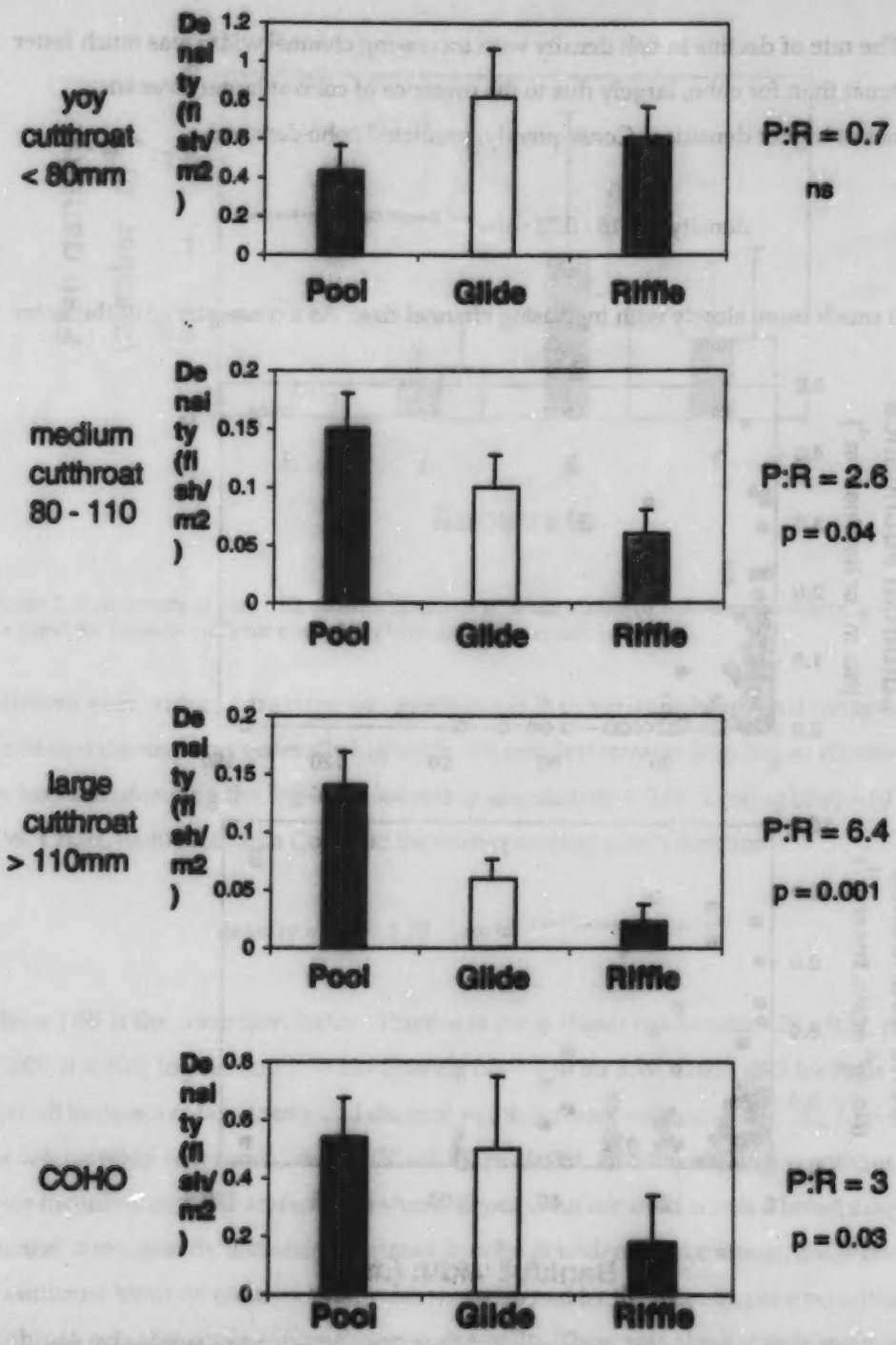


Figure 4. Density of juvenile cutthroat trout (small (< 80mm), medium (80-110mm), and large (>100mm) size-classes) and coho salmon in pools (dark bars), glides (clear bars), and riffles (speckled bars). Error bars represent ± 1 SE of the mean. Numbers in parentheses represent the ratio of fish density in pools to riffles.

downstream rate of decline in cutthroat density, fish abundance per linear meter of stream also declined with increasing stream size for cutthroat, but showed no strong trend for coho (Fig. 3b). This was true when the available rearing habitat for juvenile salmonids was assumed to be either 5 or 10 m margins along either bank of streams larger than 10 or 20 m wetted channel width.

Habitat associations within the stream channel

Patterns of fish abundance in different habitat types were size-class dependent, with a significant interaction between fish size and density in different channel unit types (split-plot ANOVA, $F_{4,134} = 2,67$, $p = 0.016$). Densities of medium and large cutthroat and coho were significantly higher in pools than in deeper channel unit types (ANOVA, $p = 0.016$, 0.001, and 0.0001, respectively; Fig. 4). In contrast, densities of smaller cutthroat were significantly lower in pools ($p=0.028$). Ratio of densities in pools:riffles increased with increasing fish size from 0.7 for small cutthroat, to 2.6 for medium-sized cutthroat, to 6.4 for large cutthroat and 3.4 for coho.

Effect of LWD on cutthroat abundance

When stream effects were controlled by pairing high and low-complexity sites within a stream, both large cutthroat (ANCOVA, $F_{1,4} = 37.6$, $p = 0.004$) and coho (ANCOVA, $F_{1,4} = 6.2$, $p = 0.068$) densities were higher in high complexity reaches. There was also a significant positive effect of both percent pool (ANCOVA, $F_{1,4} = 175$, $p = 0.0002$; Fig. 5a) and number of LWD pieces per m (ANCOVA, $F_{1,4} = 10.9$, $p = 0.03$; Fig. 5b) on density of large cutthroat trout. In contrast, there was no significant effect of complexity ($F_{1,4} = 0.01$, $p = 0.94$), percent pool ($F_{1,4} = 0$, $p = 0.97$; Fig. 5c) or LWD per m ($F_{1,4} = 0.41$, $p = 0.56$; Fig. 5d) on the density of small cutthroat trout within paired sites.

More than half of all pools in surveyed reaches (n=238) were formed by scour associated with LWD across a broad range of channel widths (1.2 to 11.1 m; Fig. 6). Maximum depths of pools formed by LWD scour were on average 10% deeper (38 vs. 34 cm, adjusted mean maximum depth) than pools formed by free-form bankscour ($Z = -2.41$, $p = 0.016$ for a Wilcoxon 2-sample rank test of relative maximum pool depth).

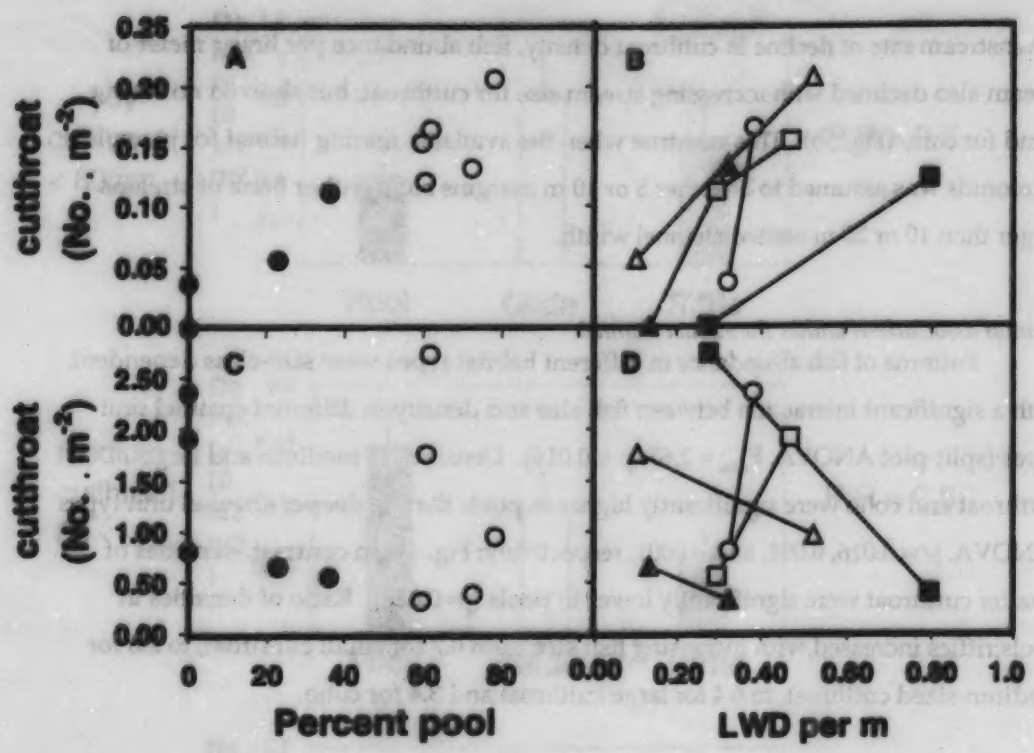
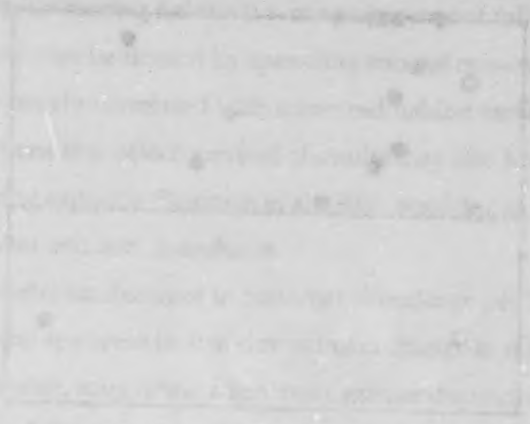


Figure 5. Relationship between density of large and small juvenile cutthroat trout and percent pool (R^2 = 0.90 for large cutthroat (A), R^2 = 0.05 for small cutthroat (C)) or LWD per linear meter of stream channel (R^2 = 0.59 for large cutthroat (B), R^2 = 0.04 for small cutthroat(D)) at paired high and low structure sites. Open circles in A and C represent high structure sites within a pair, filled circles represent low structure sites. Symbols joined by a line in panels B and D are high and low structure sites within a single stream

DISCUSSION

Our analysis indicates that stream size is the major determinant of both presence and abundance of juvenile anadromous cutthroat trout. Murphy et al. (1986) also observed a significant decline in cutthroat parr density with increasing stream size in Alaska, indicating that this pattern is probably widespread throughout the native range of coastal cutthroat trout. Coho salmon are also at high densities in smaller streams, but are present in larger channels as well. The ultimate reasons for higher cutthroat and coho densities in smaller streams are unclear. Smaller streams, particularly structurally complex ones, have relatively more edge habitat and may provide more hydraulically benign spawning, rearing and overwintering habitats than larger rivers, particularly those that lack marginal complexity associated with sidechannels and floodplain habitat.

However, competitive exclusion or predation by other salmonid species may also play a role in the longitudinal zonation of cutthroat distribution, and experiments (e.g.



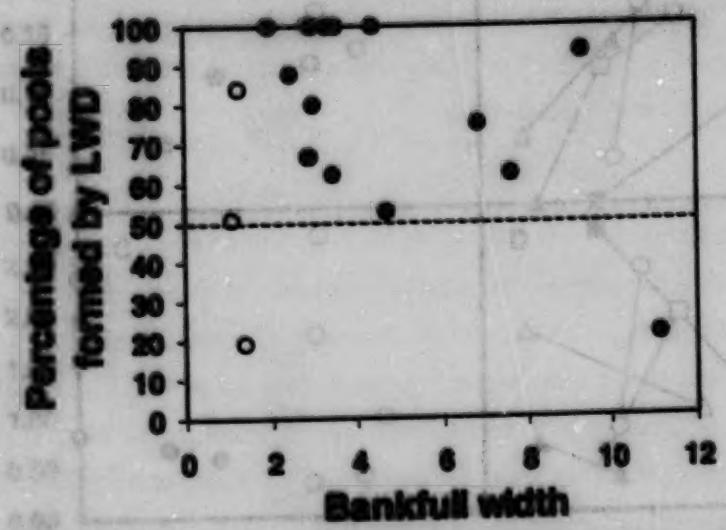


Figure 6. Percent of pools formed by LWD scour as a function of bankfull channel width. Broken horizontal line marks the 50% threshold. Open circles are S4 streams (fish-bearing streams less than 1.5m channel bankfull width).

biological interactions from differential adaptation to habitat gradients along the river continuum.

Although presence and abundance of cutthroat trout at a site appears to be primarily a function of stream size, both cutthroat and coho densities were highest in low to intermediate gradient reaches (0-5 %) dominated by gravel substrate (Fig. 2, Table 1). Consistent with our observations, Hartman and Gill (1968) also found the highest densities of cutthroat in small low-gradient streams. It is unclear whether higher cutthroat and coho densities in gravel-cobble channels are due to more abundant spawning substrate and lower extreme flows than boulder-bed channels, or the ability of LWD to more effectively force pool scour and create complex habitat in gravel-bed streams. Montgomery et al. (1999) hypothesized that high bed mobility in steep step-pool boulder channels may reduce spawning success, and this is consistent with our observations of lower cutthroat abundance in steeper boulder-bed channels.

Despite significant correlations between fish density and habitat variables, a large proportion of variance in fish abundance remained unexplained, especially for coho. Although a stochastic natural environment will always generate unexplained

variance, the extremely low R^2 for coho (0.24) indicates either that measured habitat variables were not those limiting instream abundance, or populations were limited by factors other than summer rearing habitat (i.e. streams were not fully seeded). Freshwater rearing may also be limited by spawning success or overwinter survival, both of which may be poorly correlated with measured habitat variables. Recent adverse marine conditions that affect survival of smolts may also limit coho populations below freshwater rearing capacity (Beamish et al. 1995), resulting in a weak relationship between instream habitat and fish abundance.

The rapid downstream decrease in cutthroat abundance per linear meter of stream contrasts with the apparent lack of downstream change in maximum coho abundance per linear meter, suggesting a relatively greater dependence of cutthroat on smaller streams. (Both of these patterns are robust to assumptions with respect to how much marginal habitat of larger streams is available for juvenile rearing (e.g. 10 vs. 20 m), indicating that they are unlikely to be artefacts.) No decline in coho abundance per linear meter is consistent with observations of Bradford et al. (1997) that coho smolt production is a simple linear function of stream length. This is probably not the case for cutthroat trout, where population estimates based on cumulative length of stream channels should be weighted by channel width (see Chapter 2).

Higher densities of large and medium-sized cutthroat and coho in pools (Fig. 4) indicate a preference for deeper channel units that is consistent with previous studies (Glova 1984; Heggenes et al. 1991; Lonzarich and Quinn 1995). Higher densities of young-of-the-year cutthroat in shallower channel unit types may reflect the smaller three-dimensional spatial requirements of young-of-the-year fish (Grant and Kramer 1990), which may be accommodated by pocket-pools or marginal areas of lower current velocity within a riffle channel unit (Moore and Gregory 1988). Alternatively, pools may also be preferred by smaller cutthroat, which are forced into shallower channels units by the presence of larger competitively dominant coho (Glova 1986) or older cutthroat, which will cannibalise younger year classes (Rosenfeld, personal observation). Distinguishing between preferred habitat and realized distribution for smaller cutthroat is difficult with field data, and clear definition of habitat preferences requires controlled habitat choice experiments (see Chapter 3).

Our observations that most pools in cutthroat streams are formed by scour associated with LWD supports the paradigm that LWD is the dominant pool-forming mechanism in smaller gravel-cobble streams (Fausch and Northcote 1992; Ralph et al. 1994; Richmond and Fausch 1995). This includes at least some streams as small as 1.2 m channel width in our study, although the functional significance of LWD in very small streams (<1.5m channel width) clearly needs further study. The importance of LWD in cutthroat streams is not unique to coastal British Columbia, since Connolly and Hall (1999) found that pool frequency was directly related to LWD abundance in first and second order streams in the central Oregon Coast Range, and that LWD was the best predictor of age-1 and older resident cutthroat biomass. Given that pool formation by LWD is most effective at intermediate gradients (2-5%; Beechie and Sibley 1997) where large cutthroat abundance appears to be pool-limited, long-term reduction of LWD input rates by removal of riparian forest (Murphy and Koski 1989) has the potential to seriously degrade rearing habitat for cutthroat trout.

While the slightly greater (10%) depth of pools formed by LWD scour may appear trivial, the effects of decreased pool depth on population survival may be non-linear. West coast salmonid streams in British Columbia experience a drought period during mid to late summer that often results in severe shrinkage of rearing habitat. Under severe drought conditions the entire juvenile population may be confined to one or two isolated pools (J.S. Rosenfeld, personal observation), where fish are subject to higher mortality from predation or elevated temperatures. The possibility that shallower maximum pool depth from loss of LWD as the dominant pool-forming mechanism or aggradation by sediment inputs may lead to a higher frequency of local population extinction bears some consideration.

The most robust conclusion from this part of the study is that cutthroat and coho juveniles occur at their highest densities in very small streams (less than 5 m bankfull width). While previous research has documented the importance of small seasonally dry streams as overwintering habitat for coho and cutthroat trout (e.g. Hartman and Brown 1987, Brown and Hartman 1988), this study indicates that small permanently wetted streams contribute disproportionately to summer rearing habitat for anadromous cutthroat and coho salmon in coastal watersheds.

CHAPTER 2: Distribution Of Available Habitat At A Landscape Scale (Relative Importance Of Small Streams)

ABSTRACT

The abundance of small coastal streams is often underestimated on topographic maps, and their relative contribution to total salmonid habitat within coastal drainages is poorly understood. To document the extent and distribution of streams in different channel width classes and estimate the proportion missing on topographic maps, entire stream networks were walked and surveyed in representative high and low gradient coastal topographies on the west coast of Vancouver Island, British Columbia. The amount of habitat as wetted stream surface area within a drainage was greatest in larger channels, but most of the linear length of stream was in smaller channels, especially in low gradient topographies. Fish-bearing streams less than 1.5 m wide represented 16% of total stream length and 11% of the estimated juvenile cutthroat population at summer low flow in a single representative third order drainage. Streams less than 2m channel width represented 43% of the linear channel length and harbored an estimated 39% of the juvenile trout population in the same stream, indicating a considerable contribution of smaller streams to total summer low-flow rearing habitat. Streams less than 1.5 m have the potential to contribute even more to overwintering habitat, since their proportion of total channel length increased to 23%-57% in low-gradient drainages surveyed during winter high flows. Thirty-one to 100% of fish-bearing stream length in low gradient topographies was missing on both 1:20,000 and 1:50,000 topographic maps.

INTRODUCTION

This chapter describes the distribution of available cutthroat habitat within a drainage basin and the relative contribution of small streams to total available cutthroat trout habitat, based on extensive surveys of stream habitat on the west coast of Vancouver Island. Objectives were to:

i) estimate the distribution of juvenile cutthroat populations across streams of different size,

ii) to assess how topographic relief (steep vs. low gradient) affects the abundance of small-stream rearing habitat for cutthroat trout and coho salmon, and

iii) to determine the degree to which cutthroat and coho streams are under-represented by 1:50,000 and 1:20,000 topographic maps.

This information can be used to evaluate the potential impacts of different levels of riparian protection, and can be linked to GIS-based systems to roughly estimate the distribution of anadromous cutthroat trout rearing habitat within a drainage.

METHODS

Study design

In order to estimate the proportion of streams missing on 1:20:000 and 1:50,000 maps, streams were walked on foot and channel lengths and widths systematically measured in discrete drainages. This information was also used to estimate the proportion of total stream habitat in different channel width classes for low gradient and high gradient topographies.

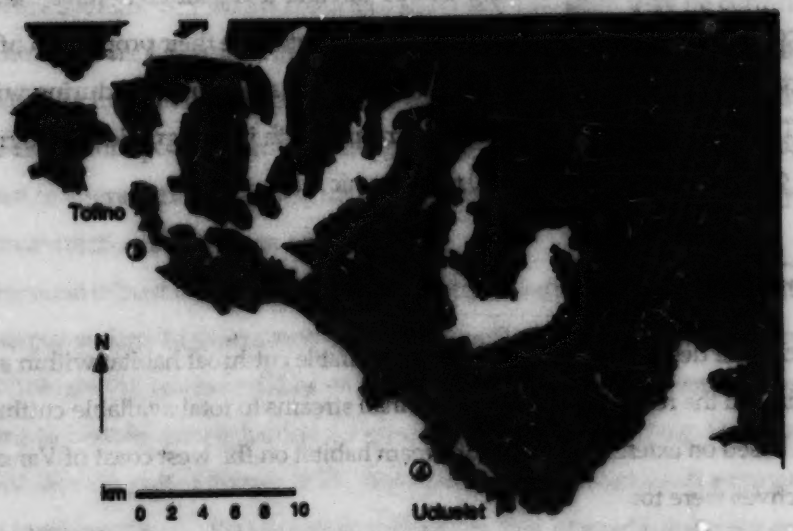


Figure 7. Locations of the areas (shaded in black) where cutthroat stream habitat was surveyed on the West Coast of Vancouver Island, British Columbia. 1=steep Tofino Inlet streams, 2=Meares Creek, 3=Tofino Peninsula streams, 4=Ucluelet Peninsula streams, and 5=Smith Creek.

Lengths of all fish-bearing reaches were measured in five areas (Fig. 7): i) a steep (34% average basin gradient, where basin gradient is basin maximum elevation divided by basin length) 10-km section of shoreline on the east side of Tofino Inlet, containing numerous small streams; ii) Meares Creek, a single drainage basin on the south side of Meares Island with a maximum bankfull channel width of 5 m at the mouth; iii) Tofino peninsula, a low-gradient area (4% average) with numerous small streams; iv) Ucluelet peninsula, an additional low gradient area (4% average) with many small streams; and v) Smith Creek, a single slightly larger drainage north of Ucluelet with a maximum bankfull channel width of 9 m at the mouth. The steep east side of Tofino Inlet and lower Meares Creek were used to compare abundance of anadromous streams in representative basins with high and low relief at summer low flow. The Tofino and Ucluelet peninsulas were surveyed during the winter to provide additional information on channel size distribution and abundance at high flows in low-gradient topographies. Meares Creek and Smith Creek were surveyed to measure the relative contribution of channels of different width to total available habitat within single discreet drainage basins. Both streams are typical coastal basins with intermediate-gradient fishless upper basins (>14.5%) ove a fish-bearing alluvial stream channel in a low-gradient lower basin (<4%).

Data collection

Stream measurement

Stream channel width was measured with a tape, and linear channel length was measured with either a tape or the distance between sequential global positioning system (GPS) locations measured along the length of the stream channel. Tofino Inlet streams and Meares Creek were surveyed during summer low flow (September 1998 and 1999). All streams were identified by carefully inspecting the shoreline by boat or on foot. Channel widths upstream of tidal influence were measured every 30-40 m using a 50 m tape, and channel length was measured as the cumulative distance between width measurements. Stream length and associated channel width measurements were made until a barrier to migration was reached (typically a falls) or

stream gradient greater than 20%. Presence of cutthroat trout during surveys at summer low flow was assessed by careful visual observation within an individual stream or tributary; presence of fish in streams surveyed during winter was determined using baited minnow traps or direct visual observation. Projections of the relative contribution of small streams to fish habitat should therefore be viewed as conservative, since fish may not have been detected in several smaller tributaries classified as fishless. Similarly, estimates of the proportion of fish-bearing streams missing on maps should also be viewed as conservative, since fish may not have been detected in all fish-bearing streams.

Streams on the Tofino and Ucluelet peninsulas and Smith Creek were walked primarily during the spring of 1999 (January-May), so that stream habitat availabilty in these areas reflects winter or spring high flows rather than summer baseflow. Location of stream channels was sequentially measured every 10-60 m (average 16.9 m, N = 2,460), or as necessary to accurately map meanders in each stream, using a Trimble Pro XLR GPS geo-referenced daily with an accuracy of $\pm$ 4 m. Bankfull width was measured at irregular intervals (mean 85 m, N = 490) or wherever there was an obvious change in channel width (e.g. a tributary mouth where it enters a mainstem). Presence of cutthroat trout, coho salmon, or other fish species in these streams was assessed using baited minnow traps or direct observation. Although summer and winter stream lengths were measured using somewhat different methodologies, both methods were fairly simple and unlikely to result in major biases between data sets.

Map measurements

Stream lengths and basin areas were measured using a digitizing tablet (Roff and Hopcroft 1986) to compare the total length of streams sampled in the field with those present on topographic maps. Streams and areas sampled in the field were located on 1:50,000 topographic maps (Canada Department of Energy, Mines and Resources) and 1:20,000 Terrain Resource Inventory (TRIM) Maps (British Columbia Ministry of Crown Lands), and watershed boundaries were drawn by interpolation of elevation contours. Land surface area in each of the five regions sampled was digitized, as was total length of stream channel above and below 20% gradient within the sampled areas. Basin gradient was calculated for Meares Creek, Smith Creek, and streams along the steep Tofino Inlet shoreline by dividing maximum basin elevation by straight-line valley

length. It was not possible to calculate basin gradient for the many small streams on the Tofino and Ucluelet peninsulas because watershed boundaries were not distinguishable; instead, average landscape gradient on each peninsula was calculated as the mean of 130 point measurements of gradient, systematically measured along a grid superimposed over each peninsula (Cheong 1996).

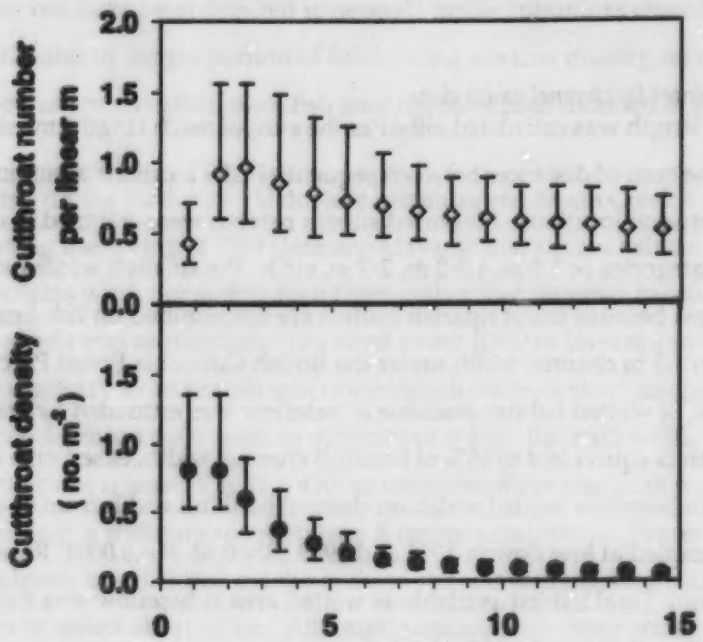
Data Analysis

Distribution of habitat by channel width class

Channel length was calculated either as the sum of reach lengths measured with a 50 m tape or the sum of distances between sequential GPS locations assuming straight-line distances between locations. Measured stream reaches were assigned to different channel width categories (< 1.5 m, 1.5-2 m, 2-3 m, etc.). The smallest width category of <1.5 m was chosen because intact riparian buffers are not required on fish-bearing streams less than 1.5 m channel width under the British Columbia Forest Practices Code.

Total area of wetted habitat available at baseflow was estimated by assuming that wetted width is equivalent to 65% of bankfull channel width, based on a regression of average stream baseflow wetted width on channel bankfull width from 86 cutthroat trout streams sampled at low flow in 1998 and 1999 (R^2= 0.62. P = 0.0001, Rosenfeld, unpublished data). Total habitat available as wetted area at baseflow was then estimated for different channel width classes.

Because average juvenile cutthroat trout densities are highest in small streams (e.g. De Leeuw and Stuart 1981; Murphy et al. 1986; Rosenfeld et al. 2000), fish population distribution by channel width class may not be proportional to wetted habitat area. Using a data set of 119 cutthroat streams sampled throughout coastal



British Columbia (including 20 sites located in the

Figure 8. Estimated cutthroat trout density per m^2 wetted area (filled circles) and number of cutthroat per linear m of stream channel (open diamonds) in midpoints of different channel width classes. Density was estimated using the power function relating density and channel width described in Rosenfeld et al. (2000; or see chapter 1), and number of trout per linear m was calculated as the product of density by wetted width. Errors bars represent 95% confidence intervals on the mean.

area described in the present study), Rosenfeld et al. (2000) documented that juvenile trout density at summer low flow was a decreasing power function of bankfull channel width (fish $\cdot$ m^{-2} wetted area = 2.06 $\cdot$ (bankfull width) $^{-1.26}$) with an R^2 of 0.55 (Fig. 8; note that 2.06 represents an average scaling factor for south and central coastal British Columbia; see Rosenfeld et al. 2000 for details). This relationship was used to calculate projected cutthroat trout numbers per linear m of stream in different channel width classes by multiplying estimated wetted width and estimated cutthroat density for Meares Creek and Tofino Inlet streams.

To prevent unrealistically high projections of cutthroat density in very small streams, juvenile cutthroat densities were assumed to asymptote at 0.8 fish per m^2 at channel widths less than 2 m (Fig. 8), which should tend to make assessment of the contribution of smaller channels more conservative. It should be emphasized that these projections of cutthroat abundance by channel width should not be interpreted as accurate predictions of cutthroat abundance for an individual stream, but rather should be viewed as the average expected densities for a population of streams. Because the cutthroat density-channel width relationship was derived for baseflow conditions, juvenile cutthroat populations could not be estimated for Smith Creek or Tofino and Ucluelet peninsula streams surveyed during winter high discharge.

To provide an estimate of habitat availability at a landscape scale for use with GIS-based mapping systems such as the British Columbia Watershed Atlas, the extent of both fish-bearing (less than 20% gradient) and total stream habitat was expressed as drainage density (km of stream per km^2 land area) in both high and low gradient topographies.

Underestimation of streams on topographic maps

The percent of streams that were missing on 1:20,000 and 1:50,000 topographic maps was calculated by comparing length of streams digitized from maps to length of streams measured in the field. The proportion missing was calculated for total stream length (all gradients) as well as fish-bearing reaches (gradient less than 20%).

RESULTS

Distribution of habitat by channel width class

The distribution of stream length in different channel width classes differed markedly between the steep gradient Tofino Inlet streams and the lower gradient valley bottom of Meares Creek. Small streams made a relatively minor contribution to total length of anadromous stream along the steeper coastline (Fig.9). In contrast, small streams contributed the majority of total fish-bearing stream length in Meares Creek (Fig. 10), where channels less than 1.5m wide and between 1.5-2 m wide contributed 16% and 27% of total linear stream habitat, respectively. Streams less than 1.5 m bankfull channel width contributed 57% of total stream length during high winter flows in low gradient Tofino and Ucluelet peninsula streams (Fig. 11), and 23% of total stream length in Smith Creek (Fig. 12).

Abundance of habitat for fish or other aquatic organisms is usually expressed in terms of habitat area. Stream habitat as wetted stream area tended to be proportionally greater in wider stream channels. While this pattern is apparent in all drainages, it is most pronounced in the drainage areas that include larger mainstem habitat: along the steep gradient Tofino Inlet shoreline (Fig. 9) and Smith Creek (Fig. 12).

The projected population of juvenile cutthroat in both Tofino Inlet streams and Meares Creek is distributed roughly proportional to linear channel length rather than habitat area (Figs. 9 and 10). This pattern is also most pronounced in larger drainages where mainstem habitat contributes disproportionately to total habitat area, but relatively little to the cutthroat population (e.g. Fig. 9). Within a single larger drainage basin (Smith Creek, Fig. 10), the majority of stream habitat in terms of area is in channels greater than 3 m wide, whereas the majority of stream length is in channels less than 3 m wide.

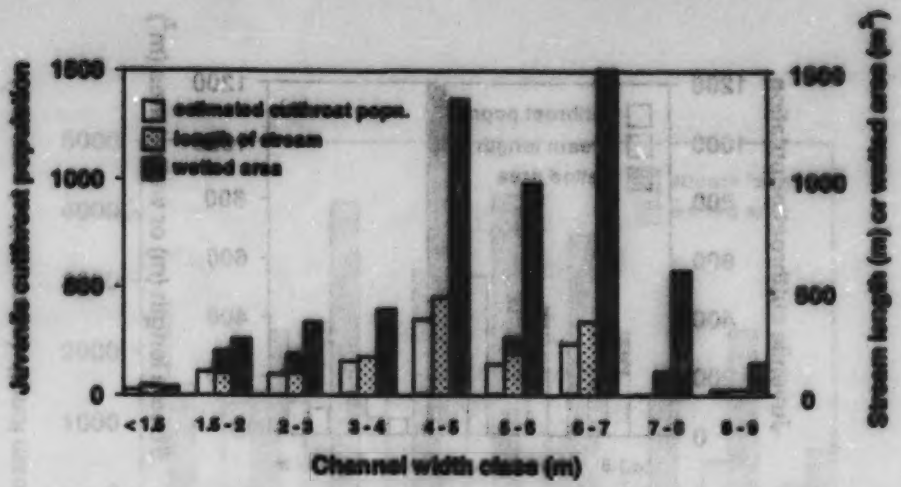


Figure 9. Bar graph showing the distribution of estimated juvenile cutthroat population, stream length, and wetted stream area in different channel width classes at summer low flow for all Tofino Inlet streams combined. Black sections of bars represent reaches that were considered to be fishless at low flow because they were either dry or above the most upstream observation of fish in a tributary.

Topographic effects on drainage density and abundance of anadromous habitat

The steep gradient Tofino Inlet streams had short anadromous reaches of 33 - 280 m. The total 1,440 m of streams accessible to anadromous fish on the steep east side of Tofino Inlet was roughly equivalent to the length of anadromous stream in the low-gradient valley bottom of Meares Creek, although it was only a fraction of the basin area (Table 2). Total stream drainage density varied little among the four lower gradient topographies (Meares and Smith creeks and the Tofino and Uchuelet peninsulas; Table 2), but was roughly 50% lower along the steep side of Tofino Inlet. In contrast, drainage density of anadromous reaches was an order of magnitude lower along the steep topography of Tofino Inlet (Table 2). Drainage density of anadromous reaches in the lower gradient valley bottom of Meares Creek where streams were concentrated was as high as 6.40 km of stream per km^2. As with total length of anadromous stream, estimated total cutthroat populations in Meares Creek and the combined Tofino Inlet streams were similar (Table 2). Juvenile cutthroat trout density per km^2 of drainage

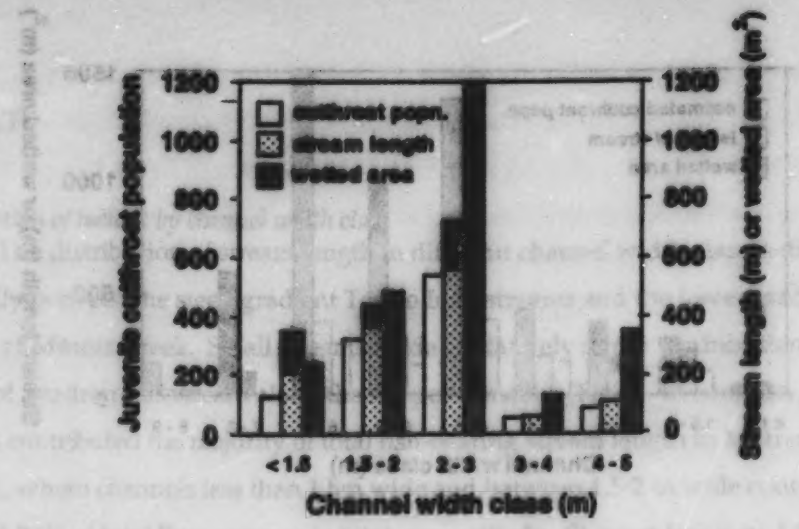


Figure 10. Bar graph showing the distribution of estimated juvenile cutthroat population, stream length, and wetted stream area in different channel width classes at summer low flow in Meares Creek. Black sections of bars represent reaches that were considered to be fishless at baseflow because they were dry or above the most upstream observation of fish in a tributary.

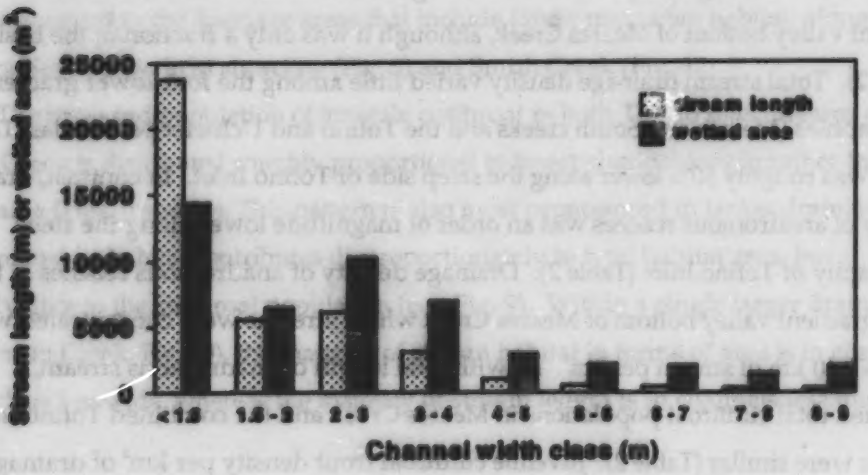


Figure 11. Bar graph showing the distribution of stream length and wetted stream area in different channel width classes during winter high flows for Tofino and Ucluelet peninsula streams combined.

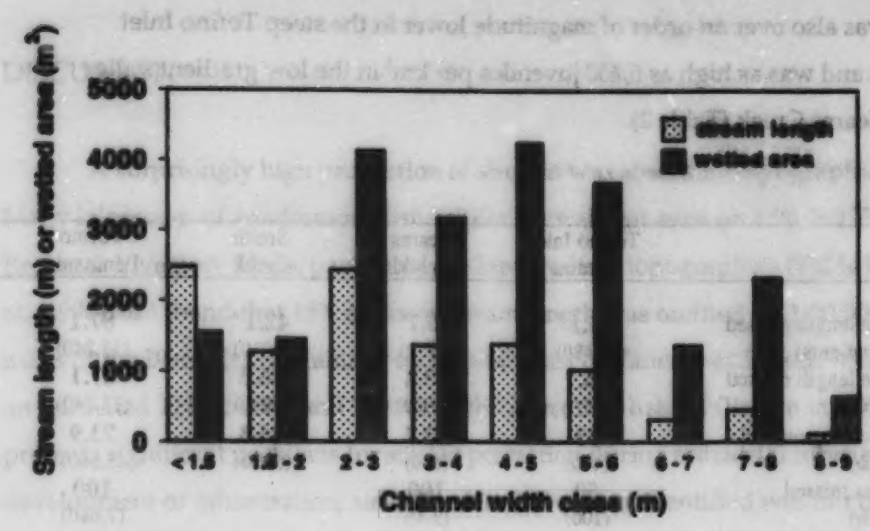


Figure 12. Bar graph showing the distribution of stream length and wetted stream area in different channel width classes during winter high discharge for Smith Creek.

	Tofino Inlet streams	Meares Creek	Smith Creek	Tofino Peninsula	Ucluelet Peninsula
Average basin gradient (%)	34	30.9[c] / 3.6[b]	14.5[a] / 3.0[b]	3.5[c]	3.7[c]
Drainage basin area (km^2)	17.85	1.70	5.75	8.30	11.75
Total stream length (km)	21.83	4.96	11.95	15.20	26.27
Total anadromous stream length (km)	1.44	1.28	10.85	7.52	9.43
Drainage density (km/km^2)	1.22	2.92	2.08	1.83	2.24
Anadromous drainage density (km/km^2)	0.08	0.75[a] / 6.40[b]	1.89[a] / 2.25[b]	0.91	0.80
Estimated juvenile cutthroat population	1140	1090			
Juvenile cutthroat density ($no./km^2$)	64	640[a] / 5450[b]			

[a] for entire drainage basin
[b] for lower anadromous section of basin
[c] for entire peninsula

Table 2. Basin and stream characteristics and estimated cutthroat populations for the different areas sampled.

basin area was also over an order of magnitude lower in the steep Tofino Inlet topography, and was as high as 5,450 juveniles per km^2 in the low gradient valley bottom of Meares Creek (Table 2).

	Tofino Inlet streams	Meares Creek	Smith Creek	Tofino Peninsula	Ucluelet Peninsula
1:50,000					
% stream length missed	25.1[a]	35.7[a]	42.1[a]	87.1	100
(all gradients)	(5,480)	(1770)	(5030)	(13,240)	(26,270)
% stream length missed	36.7	63.2	46.3	87.1	100
(< 20%)	(670)	(1,060)	(5030)	(13,240)	(26,270)
% fish-bearing missed	33	52.7	46.3	73.9	100
(< 20%)	(480)	(690)	(5030)	(5,560)	(9,430)
% fishless missed	50	100	–	100	100
(< 20%)	(200)	(370)		(7,680)	(16,840)
1:20,000					
% stream length missed[b]	–	–	–	100	100
(all gradients)				(15,200)	(26,270)
% stream length missed	13.2	63.2	31.0	100	100
(< 20%)	(240)	(1,060)	(3,710)	(15,200)	(26,270)
% fish-bearing missed	3.1	52.7	34.2	100	100
(< 20%)	(45)	(690)	(3,710)	(7520)	(9,430)
% fishless missed	50	100	–	100	100
(< 20%)	(200)	(370)		(7,680)	(16,840)

[a] stream reaches missed include low gradient walked reaches and steep gradient (>20%) reaches that were not walked but are present on 1:20,000 topographic maps.
[b] high gradient reaches (> 20%) were not walked in Tofino Inlet streams, Meares Creek, or Smith Creek, so that the degree of underestimation of steep reaches on 1:20,000 cannot be assessed. All stream reaches were walked on the Tofino and Ucluelet Peninsulas.

Table 3. Proportions of streams missing on 1:50,000 and 1:20,000 topographic maps for the different areas sampled.

Underestimation of streams on topographic maps

Underestimation of total stream length on topographic maps varied from 13.2-100% (Table 3). Underestimation was least pronounced in the high gradient Tofino Inlet region, although a full 33% of anadromous stream length was missed at the 1:50,000 scale, dropping to 3.1% at 1:20,000. Underestimation of streams was most pronounced on the low gradient Ucluelet peninsula, where virtually none of the 26 km of measured stream channel (including approximately 9.4 km of potentially fish-bearing stream) appeared on either 1:20,000 or 1:50,000 topographic maps (Table 3). Although 1:20,000 maps tended to show more streams than 1:50,000 maps, underestimation of fish-bearing stream length at the 1:20,000 scale still ranged from 34.2-100% in the lower gradient topographies (Table 3).

DISCUSSION

A surprisingly high proportion of streams was absent on topographic maps. Many kilometers of anadromous fish habitat were absent even on 1:20,000 Terrain Resource Inventory Maps, particularly in low gradient topographies (Table 2). Brown et al. (1996) also found that 48% of linear stream length was omitted on 1:20,000 TRIM maps of the Black Creek drainage on the east coast of Vancouver Island, which included an estimated 12% of coho and 20% of cutthroat rearing habitat (Brown et al. 1999). This presents significant problems for stream protection during industrial forestry development or urbanization, since streams that are not identified will not be accommodated during development plans, and are less likely to be protected during resource extraction or urbanization (e.g. Forest Practices Board 1998). Our analysis indicates that there is no real substitute for careful field surveys to document location and extent of streams where development is planned, although careful air photo interpretation will likely identify a significant number of streams that are not present on topographic maps.

Since GIS-based stream projections such as the B.C. Watershed Atlas are based on 1:50,000 topographic maps, gross underestimates of small stream habitat obviously presents serious limitations to the development of GIS-based models for estimating fresh-water rearing capacity for juvenile cutthroat trout or other salmonids. Topographic maps are digitized from air photographs, where stream drainages are usually most apparent in high gradient topographies with incised channels, and least obvious in low gradient landscapes. While topography-based correction factors for biased underestimates of small stream density are possible, the number of streams missed on any given projection will also depend on the skills of the individual cartographer who digitized the air photographs. Nevertheless, cutthroat population density and fish-bearing stream drainage density projections derived in this study (Table 2) can be linked to GIS-based models to roughly estimate cutthroat trout habitat capacity in different coastal landscapes, either to identify areas for field inventory, or to generate rough estimates when funding for field surveys is unavailable. Although this study specifically targeted habitat of coastal cutthroat trout that was likely to be

anadromous, it is worth noting that over 50% of the fish-bearing streams that were absent on topographic maps on the Uchu let and Tofino peninsulas also contained coho salmon. This is consistent with the substantial underestimation of coho habitat on 1:20,000 topographic maps observed by Brown et al. (1996, 1999).

Density of small streams is a function of both climate (rainfall) and vegetation cover (Gregory 1976; Knighton 1984), and maps may well overestimate the abundance of small fish-bearing streams in drier climates where forest cover is discontinuous and vegetation is less likely to obscure stream channels on air photographs. However, underestimation of small streams as documented in this study is probably a general feature in wetter coastal climates with continuous forest cover and high wetted stream density. Since topographic maps are generated with similar methodologies in different jurisdictions, underestimation of small streams is likely widespread throughout the wet coastal regions of the Pacific Northwest.

Despite occurring at their highest densities in small streams (De Leeuw and Stuart 1981; Murphy et al. 1986; Rosenfeld et al. 2000), the net effect of increasing channel width and decreasing cutthroat density downstream is a slow decline in projected cutthroat abundance per linear m (the product of density and wetted width) as channel size increases. Consequently, the distribution of juvenile cutthroat population by channel width class appears to more closely approximate the linear length of stream channel than habitat area over the range of channel widths (less than 9 m) included in this study. This observation is similar to the results of a regional analysis of habitat factors influencing coho production (Bradford 1997) that found linear stream length to be the single best predictor of coho smolt production.

Expressing fish population distribution as a function of channel width is a useful way to evaluate riparian protection regulations that are based on channel size. Of particular interest is the proportion of fish-bearing reaches less than 1.5 m channel width, since these streams receive a maximum retention of 25% of riparian trees across a landscape in coastal British Columbia and may be cross-stream yarded during logging (British Columbia Ministry of Forests 1995). Although streams less than 1.5 m channel width contributed to only 3% of total anadromous stream length and 1% of the projected cutthroat population in the steep Tofino Inlet streams, channels less than 1.5 m width

constituted 16% of the linear habitat at summer low flow and 11% of the projected fish population in lower gradient Meares Creek.

The contribution of channels less than 1.5 m width also increased greatly during winter and spring high discharge conditions as seasonally dry channels became wetted (Figs. 11 and 12). While this observation needs to be qualified by the fact that we did not control for basin effects (e.g. by measuring seasonal changes in wetted channel length in a single drainage), the increased contribution of small channels during high flow observed in this study is consistent with previous studies (Bustard and Narver 1975; Tschaplinski and Hartman 1983; Hartman and Brown 1987; Brown and Hartman 1988) and the expectation of greatly increased wetted tributary habitat during periods of increased rainfall (Knighton 1984). It has been documented that both juvenile cutthroat trout and coho salmon can move upstream into small seasonally dry tributary streams to overwinter (Hartman and Brown 1987; Brown and Hartman 1988), so that much of this seasonally wetted habitat will be available for overwintering even if it is unavailable for summer rearing.

Of equal note is the fact that streams between 1.5-2 m wide contributed 22% of the length and 29% of the projected juvenile trout population in Meares Creek during summer base flow. This is of concern because of the potential for streams in the 1.5-2 m width class to be misclassified as less than 1.5 m if channel widths are selectively measured in narrow sections rather than systematically along the channel length. This may be a general problem with riparian regulations that index level of protection to stream size (e.g. British Columbia Ministry of Forests 1995) or discharge (Oregon Department of Forestry 1995), and may inadvertently cause habitat protection to default to a lower level associated with a smaller stream class (Forest Practices Board 1998). Until recently, Washington State also recognized a class of fish bearing streams less than 1.5 m channel width (Washington Department of Natural Resources 1995). However, the Washington State riparian classification system has since been replaced with a simpler one that recognizes fish-bearing stream channels greater or less than 3 m, and riparian retention is now structured so that riparian basal area will approach that of a mature forest in 140 years. In contrast with riparian protection on very small fishless streams in British Columbia, both Alaska and Oregon states have 30 and 6 m riparian reserves

zones, respectively, on anadromous streams on state land irrespective of channel width (Oregon Department of Forestry 1995; Alaska Department of Natural Resources 2000).

The analysis presented in this study focuses on the importance of small fish-bearing streams from the perspective of their direct contribution to fish habitat. Small fishless headwater streams also serve less directly quantifiable ecosystem functions that affect downstream fish habitat, including the storage, retention, and processing of organic matter (Wallace et al. 1997, 1999), and production and export of both terrestrial and aquatic invertebrates (Wipfli 1997). In the interests of multi-species management, it is also important to recognize that fishless headwater streams provide habitat for potentially unique invertebrate communities as well as a diversity of amphibians that do not usually co-exist with fish (Kats et al. 1988; Corn and Bury 1989).

This study documents the disproportionately large contribution of small streams as potential cutthroat trout rearing habitat in coastal drainages, and highlights the need for riparian regulation and land-use management practices that adequately protect small streams. This is becoming increasingly urgent in the Pacific Northwest, as continued urbanization, agriculture, and logging in low-gradient landscapes exerts increasing pressure on small stream habitat and their associated fish stocks (Murphy 1995; Reeves et al. 1997). Although the specific conclusions of this study apply primarily to coastal streams of northwestern Canada and the United States, the universal geometry of drainage networks is such that small streams are always more abundant than larger ones, and the connectivity of lotic systems dictates that small headwater streams cannot be lost without compromising the integrity of both downstream reaches and headwater species.

CHAPER 3: Effect of Channel Structure on Juvenile Growth

ABSTRACT

In order to assess freshwater habitat requirements of juvenile anadromous cutthroat trout, we measured habitat preference and growth rates of young-of-the-year (yoy) and 1-2 year old fish confined to either pools or riffles during summer low-flow. Habitat preference experiments indicated that yoy cutthroat trout preferred pools to riffles, despite normally occurring at lower ambient densities in pools. Growth experiments demonstrated that yoy fish grew in both pools and riffles, although growth rates were higher in pools. Larger juvenile trout grew on average in pools but consistently lost weight in riffles, indicating that pools are a habitat preference for yoy trout but a requirement for larger fish during summer low-flow.

INTRODUCTION

The third chapter of this report describes the results of experiments conducted in 1999 to evaluate growth rates of juvenile cutthroat in different habitat types in Husdon Creek near Sechelt (Rosenfeld and Boss 2001). Goals of these experiments were to determine the ability of juvenile cutthroat trout to grow in pool vs. riffle habitat during summer low-flow, since abundance of pools frequently declines in streams that have been impacted by logging, urbanization, or agriculture. Specific objectives were:

i) to assess preference of yoy cutthroat for pool vs. riffle habitat at summer low-flow

ii) to measure growth and survival of yoy and larger (1-2 year old) cutthroat in pool vs. riffle habitat.

The implications of differences in habitat –specific growth rates for cutthroat responses to habitat change are considered in the discussion. Habitat management considerations are included in the last chapter at the end of the report.

METHODS

Study design

Growth experiments

Growth rates of yoy (40-60mm) and larger (120-160mm) cutthroat juvenile trout during summer low-flow were measured by confining fish to enclosures installed in either pool or riffle habitat. Growth experiments were performed in Husdon Creek, a small coastal stream with an average bankfull width of 3.5 m and a summer baseflow of approximately 30 l s^{-1}. Husdon Creek was chosen because of logistic constraints and because it typifies the small stream habitat where juvenile anadromous coastal cutthroat trout are most abundant (Rosenfeld et al. 2000). The Husdon Creek drainage basin is primarily second growth forest with a drainage area of 3.4 km^2. The fish community consists of cutthroat trout in three age classes (yoy, 1+, and 2+ fish) and juvenile coho salmon. Cutthroat and coho densities are relatively high, averaging 0.92 and 0.2 fish m^{-2}, respectively (J. Rosenfeld, unpublished data). The reach of stream used for experiments had approximately 75% canopy cover, a 1% gradient, substrate dominated by gravel and sand, and abundant large woody debris (LWD; 0.37 pieces of LWD per linear m) in a forced pool-riffle channel.

Enclosures were created by fencing off individual channel (habitat) units using 6.5 mm wire mesh (hardware cloth). Wire mesh supported by re-bar (steel re-enforcing rod) was installed across the top and bottom of each pool or riffle, with the bottom skirt stapled to a wooden 2x4 buried under the substrate. Substrate and cover within each channel unit were left intact. The 6.5 mm mesh was permeable to most invertebrates in the stream with the exception of the largest instars of the stonefly *Pteronarcys sp.*. A total of 8 pools and 7 riffles were enclosed over a 400 m reach of stream, with 5 channel units as isolated enclosures and the remaining 10 as adjacent channel units in four separate groups. Channel units were selected based on their obvious classification as pools or riffles (see Table 1 for differences in depth and velocity between habitats), and the additional criteria that fences could be installed without major habitat disturbance (e.g. removal of LWD). Channel units that met these criteria were more of less randomly distributed throughout the reach, and were similar in depth and surface area to pools and riffles surveyed over a 600 m length of stream including the study reach. Although all enclosures had sufficient instream cover (cutbank, boulder, small or large woody debris) for refuge from terrestrial

predation, cover in riffles was usually not associated with the more optimal foraging locations where fish could observe drifting invertebrates. To test whether cover was limiting to growth of large fish in riffles and pools, a 45 cm wide strip of 3 mm Vexar screening attached to a wooden frame was placed across the stream 5-10 cm above the water surface in 3 riffles and 3 pools.

Habitat	area (m^2)	mean depth (cm)	maximum depth (cm)	mean velocity ($cm \cdot s^{-1}$)
Pool	14.4 (8.0-22)	21.6 (16.7-25.4)	45.4 (37-51)	6.6 (3.9-8.9)
Riffle	7.4 (5.3-9.1)	6.2 (5.0-7.7)	14.1 (12-18)	21.0 (15.6-24.5)

Table 4. Physical characteristics of pools (n=8) and riffles (n=7) used for growth experiments. Values are means with range in parentheses.

Because of the limited number of enclosures, growth rate experiments with yoy and older trout were run sequentially. All 15 enclosures were used to measure growth rates of larger juvenile cutthroat from June 28 to Aug. 3, and 8 enclosures were used to measure growth rates of yoy fish from Aug. 5 to Aug. 31. Growth of larger fish was measured first because yoy trout were too small to be retained by a coarse mesh until the beginning of August. Stream temperature was similar in July and August, averaging 11.4 and 12.4 °C, respectively. Fewer replicates were used for yoy growth because yoy were stocked at a higher density than larger trout, and were therefore less subject to loss of replication through individual mortality.

Fish were removed from enclosures prior to stocking using minnow traps and multi-pass electrofishing. Large fish stocked in enclosures were captured with minnow traps from the reach in which the experiments were performed. Large fish were stocked at a relatively low density (0.17 fish·m^{-2}) to ensure that density-dependent effects did not confound habitat effects, and fish were stocked at equivalent densities in pools and riffle. Fewer large fish were stocked in pools than were captured in pools; however, large fish were not captured from riffles. Most enclosures had a relatively small surface area and were stocked with a single fish, but three of the larger pools received 2 fish and the largest pool received 3 fish. All fish were uniquely marked subcutaneously with visible implant elastomer (Northwest Marine Technology, Shaw Island, WA) to permit measurement of individual growth rates. Following marking, fish were held overnight to clear stomach

contents, weighed to the nearest 0.01 g, measured to the nearest mm, and stocked in enclosures. Fish were collected 36 days later using minnow traps and electroshocking, and were again weighed and measured after being held overnight to clear gut contents.

Because many yoy fish were small enough to pass through a 6.5 mm mesh, a 3 mm mesh was placed over the original fencing. Yoy fish were stocked at the relatively low density of 0.5 fish $\cdot$ m^{-2} to prevent density-dependent effects. Yoy were collected by electrofishing because of low capture rates in minnow traps. Yoy fish were individually marked, held overnight, weighed and measured, and released into four pools and four riffles from Aug. 5-6. Fish were recovered from enclosures by electrofishing after 27 days, and again weighed and measured after being held overnight. Screens were cleaned daily or as necessary to maintain natural flow in enclosures.

Habitat preference of yoy

To assess habitat preference of yoy trout, we removed the center fence separating three replicate pool-riffle sequences and replaced it with a fine-mesh stop-net buried beneath the substrate surface. We stocked individually marked fish at roughly equal densities (0.55 ± 0.13 fish$\cdot$ m^{-2}SD) in both pools and riffles on Aug. 8, leaving fish free to move between habitats within each replicate pool-riffle sequence. Fewer fish were stocked in riffles than pools because riffles had smaller surface areas. Pools and riffles were isolated one week later when concealed observers on the stream bank quickly lifted buried stop-nets by pulling on ropes attached to net-ends. Fish were then recovered from separate pool and riffle habitats by multiple pass electroshocking.

To examine the potential effect of predation by larger trout on yoy distribution, stop-nets were buried again and fish were returned to the channel unit from which they were collected in each pool-riffle sequence. Large cutthroat trout (124-173 mm) were then stocked in pools at twice the density used in the growth rate experiment. Stop-nets were again raised and fish collected after one week.

Data analysis

Growth rate

Relative daily growth rate of individual trout was calculated as final weight less initial weight divided by duration of the experiment and initial body weight. When more than one fish were present in an enclosure, growth rate was estimated as the average for all

fish in that enclosure. Size (yoy *vs.* larger trout) habitat (pool *vs.* riffle) and cover (screen addition *vs.* no screen addition) effects on growth were analyzed as a three-way analysis of variance (ANOVA, n=23) following log (x + 0.008) transformation to normalize data and remove correlation of variance with the mean. Effects on growth were reanalyzed as a two-way ANOVA because one of the factors (screen addition) was not significant. The constant a in log $(x + a)$ transformation was selected based on the criterion of maximizing normality of regression residuals (Berry 1987), which was assessed using the Shapiro-Wilke statistic (SAS Institute 1989) and a frequency histogram of residuals. Homogeneity of variance in ANOVA was evaluated by testing for a significant correlation between the absolute value of residuals and predicted values. All analyses met assumptions of normality and homogeneity of variance at $p = 0.05$. Data analysis were performed using PC SAS (SAS Institute 1989).

To better describe the effect of habitat on trout over a broad range of fish size (rather than as two size-classes), relative growth rate for all individual fish (n=45) was regressed against initial fork length. Although individual fish from the same enclosure are not independent and cannot be treated as separate observations without inflating probability values (c.f. pseudoreplication), trout are territorial and growth rates of individual fish were somewhat independent insofar as they experienced different micro-environments within each enclosure. Relative growth rates were log (x + 0.007) transformed to normalize variance and remove correlation of residuals with the mean. The log-log relationship of growth rate on fork length was back-transformed to its arithmetic power function to facilitate interpretation. To adjust for the inherent bias in backtransformation of logged relationships, a correction factor for scaling backtransformed logged values to arithmetic means was calculated as $CF = e^{0.5SE/2/2.303}$ (Sprugel 1983, Baskerville 1971).

Yoy habitat choice

Change in distribution between pools and riffles during habitat preference experiments was expressed as the change in initial and final densities in riffles (evaluated as a paired t-test, n=3), and as differences in final yoy densities between pool and riffle habitats (n=3).

RESULTS

Growth rate

All large cutthroat trout were recovered from enclosures with no mortality over the course of the experiment. From 33 to 100% of yoy fish were recovered from each enclosure (average of 67%

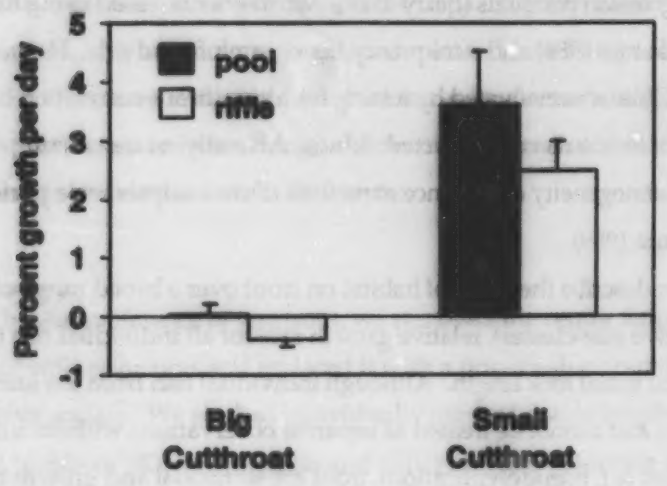


Figure 13. Average growth rate (percent body weight per day) of small and large juvenile trout in pools and riffles.

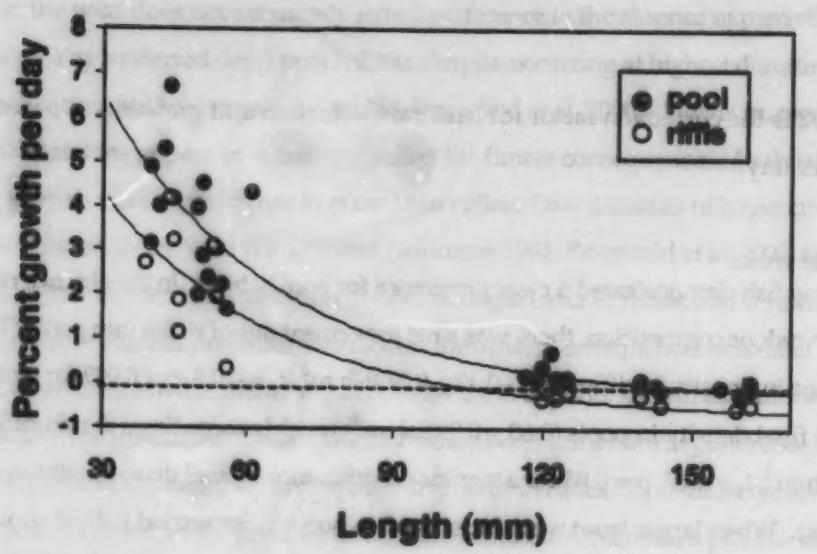


Figure 14. Growth rates (percent body weight per day) of individual juvenile cutthroat trout in pool and riffle habitat as a function of body length.

in riffles and 82% in pools), which is probably an overestimate of yoy mortality, since stunned or killed yoy may not have been recovered in the complex natural stream habitat of enclosures despite multiple pass electrofishing.

There was no significant effect of cover (screen) addition on growth rate of large cutthroat ($F_{1,12} = 1.2$, $p = 0.30$). There was a significant size ($F_{1,20} = 238.5$, $p < 0.0001$) and habitat ($F_{1,20} = 24.4$, $p < 0.0001$) effect on average relative growth rate within enclosures (Fig 13). Growth rates for yoy fish were positive in both pool and riffle habitat, although growth was lower in riffles. In contrast, growth rate of larger cutthroat was positive in pools, but negative in riffles. Growth rates for individual fish showed a typical allometric decline in relative growth rate with increasing size (Fig. 14), with growth consistently higher in pools than riffles across the entire range of fish length ($F_{1,44} = 42.6$, $P < 0.0001$). Relative growth rate was best described by backtransforming the log-log relationship (log (growth + 0.007) = 1.44 –1.82(log length) + (0 for riffle, 0.29 for pool), R^2=0.92) to the corresponding power function

% growth = ((27.5 · length$^{-1.02}$ · (1.94 for pool habitat, 1 for riffle habitat)) – 0.007) · 1.02 · 100

where 1.02 is the correction factor for backtransformation and growth is in percent body weight per day.

Yoy habitat choice

Yoy fish demonstrated a clear preference for pool habitat. In the absence of predation risk or competition, there was a net movement out of riffles into pools (Table 5). The change in density in riffles was –0.42 ± 0.07 fish m^{-2} (t_2 = -10.8, p = 0.009 for a paired t-test) with final density in pools (0.63 ± 0.09 fish m^{-2}) roughly three times that in riffles (0.23 ± 0.13 fish m^{-2}; t_2 = 4.47, p = 0.01 for a significant difference in final density between pools and riffles). When larger trout were introduced to pools in the second habitat choice experiment, there was no significant effect on yoy distribution (t_2 = 1.13, p = 0.32 for a difference in final density between habitats). However, there was a net movement of fish into riffle habitat in the pool-riffle sequence with the least instream pool cover (Table 2), suggesting that the effect of predation on habitat choice is dependent on availabilty of

	Initial number		Final number		Change in	instream
	pool	riffle	pool	riffle	riffle	cover (m^2)
No large fish	7	4	10	1	-3	2.5
	7	4	9	2	-2	2.7
	5	4	8	1	-2	0.8
Large fish addition	10	1	10	1	0	2.5
	9	2	8	1	-1	2.7
	8	1	5	4	+3	0.8

Table 5. Number of yoy cutthroat trout at the start and end of habitat choice experiments in the absence and presence of larger predatory trout for three replicate pool-riffle sequences.

instream cover. When the buried stop-net was raised in this sequence, one of the larger trout was observed trying to swim back into the pool from the riffle and regurgitated a marked yoy when recovered, demonstrating that predation risk for yoy was substantial.

DISCUSSION

Habitat choice experiments with yoy trout clearly demonstrated that habitat selection in the wild does not accurately reflect preference in the absence of predation and competition. Yoy preferred deep pool habitat, despite occurring at highest densities in shallow habitats in field surveys (Glova 1984, Rosenfeld et al. 2000). However, preference for pool habitat does appear to accurately reflect the fitness consequences of habitat choice, since yoy growth rates were higher in pools than riffles. Low densities of larger cutthroat in shallow habitats in the wild (Fausch and Northcote 1992; Rosenfeld et al. 2000) is also consistent with observed negative growth rates of larger trout in riffles, and confirms that habitat selection by larger juveniles also reflects the fitness consequences of habitat use.

Differential growth rates of yoy and larger trout in pools and riffles indicate different habitat requirements at summer low-flow. Pools are a habitat preference for yoy, but not a requirement, since they are capable of growth in riffles. In contrast, pools are a habitat requirement for larger juvenile trout, which could not maintain a positive energy balance in riffles. Negative growth in riffles supports the paradigm that riparian management practices leading to a loss of pool habitat (e.g. through decreased LWD inputs; Murphy and Koski 1989) causes a decline in suitable rearing habitat for older fish. This emphasizes the importance of pools at a population level, since the freshwater rearing phase of anadromous cutthroat in small gravel-cobble streams is probably limited by the number of 1-2 year old smolts rather than by yoy abundance (Fausch and Northcote 1992).

Although fish predation has been widely demonstrated to influence habitat use by juvenile fish (Werner and Hall 1988; Gilliam and Fraser 1987), the effect of introducing large cutthroat to pools in the habitat preference experiment was ambiguous. While there was no effect of large trout on yoy density in the two pools with abundant cover (Table 5), there was net movement out of pool habitat in the pool with the least cover, suggesting that predator effects on habitat choice are cover dependent. Alternatively, competitive displacement by larger coho juveniles that hatch earlier in the spring and also prefer pools (Glova 1986; Nickleson et al. 1992) may be a more important factor displacing yoy into riffles than cannibalism, particularly at high coho densities or when instream cover is abundant. This is both a management and conservation issue, since stocking juvenile coho on top of native cutthroat stocks is common in coastal streams. The net outcome of coho-cutthroat interactions are potentially complex (Polis et al. 1989), since coho juveniles are

both a competitor with yoy trout and a prey item for older fish, but stocking coho appears to contribute to long-term declines of cutthroat trout in coastal streams (Johnson 1999).

Selection of deeper pool habitat by larger fish is usually attributed to use of pools as refuges from avian or terrestrial predators (Power 1984; Lonzarich and Quinn 1985). We observed zero mortality of larger juvenile trout in either pools or riffles over the 30-day growth experiment, indicating little effect of terrestrial predators even in shallow habitats. In contrast, Lonzarich and Quinn (1995) showed that predation, most likely by herons, resulted in up to 50% mortality of larger juvenile steelhead trout in shallow pool habitat in small artificial channels adjacent to a larger stream in Washington. Lower mortality rates in Husdon Creek may reflect lower abundance of avian predators in small forested streams, in contrast with higher densities of wading or diving birds in estuaries or riparian corridors adjacent to larger streams and rivers. Differences in mortality rates highlight the spatially variable nature of predation risk from terrestrial predators in small streams (e.g. Heggenes and Borgstrom 1988), which will influence survival and habitat selection to unknown degrees.

The habitat-specific growth model (Fig. 14) indicates that juvenile cutthroat trout need to shift from riffles to pools at approximately 90 mm in order to maintain a net energy balance at summer baseflow. This is analogous to the ontogenetic habitat shift of juvenile bluegill sunfish from the littoral zone of lakes to the more resource rich but predator abundant pelagic zone (Werner and Hall 1988). Werner and Hall attributed this size-dependent habitat shift to a trade-off between lower resource acquisition in the littoral zone vs. greater predation risk from gape-limited predators in the pelagic zone. However, while the presence of yoy trout in riffles represents a probable trade-off between lower resource acquisition in riffles vs. greater predation risk in pools (or interspecific competition from coho), the shift of larger trout out of riffle habitat appears to be driven by a ceiling on maximum energy intake imposed by the habitat structure of shallow riffles, rather than a trade-off between predation risk and resource acquisition.

Despite higher overall growth rates of cutthroat in pool enclosures, the largest trout marginally lost weight even in pools. By removing forage fish (yoy cutthroat and coho) from enclosures prior to stocking, we forced larger cutthroat to feed exclusively on invertebrates. Larger juvenile trout appear to be energy-limited by a diet of invertebrate drift even in pools, indicating the requirement for an ontogenetic dietary shift to facultative

piscivory to maintain positive growth as they become larger. Despite a shift to piscivory, maximum energy gain in small-stream habitat probably remains limited by pool size and prey encounter rate, selecting for the final ontogenetic habitat shift of migration to the ocean where habitat structure no longer limits energy intake.

Understanding the mechanisms underlying growth in different habitats is a useful first step towards defining both habitat requirements and adaptive constraints on habitat use. Human land use practices frequently alter the complex habitat structure that characterizes stream channels, thereby affecting the survival of both individuals and populations. Logistic constraints often prevent the large-scale habitat perturbation experiments that are ideal for documenting the population-level effects of habitat change in streams (e.g. Hartman and Scrivener 1990). This study demonstrates an alternative way to infer population-level consequences of habitat change by measuring the fitness consequences of using sub-optimal habitats (e.g. riffles) which may become more abundant following disturbance.

CHAPTER 4: Synopsis Of Juvenile Cutthroat Trout Habitat Requirements And Implications For Forestry Impacts

Habitat requirements

Landscape/basin requirements

Based on extensive habitat surveys described in this study (Chapter 1) and elsewhere (Murphy et al. 1986; Hartman and Gill 1968; DeLeuuw and Stuart 1981), both juvenile cutthroat trout and coho salmon occur at their highest densities in smaller stream channels (less than 5m, Fig. 1; classified as S3 and S4 under the FPC), and densities decline rapidly as streams become larger. This is a habitat association rather than a demonstrated habitat requirement, but it strongly suggests that smaller streams are the most suitable spawning and rearing habitat for these species. Both cutthroat and coho densities are typically highest in lower gradient streams with substrate dominated by gravel and fines, and lowest in steeper gradient streams dominated by boulder substrate (Chapter 1, Figs. 1 and 2).

Because of the hierarchically branching nature of stream drainage networks, smaller streams contribute far more to total linear stream habitat than larger downstream channels, which contribute proportionally more to habitat area (see Chapter 2). Because cutthroat trout densities decline as streams become larger, juvenile trout abundance is roughly proportional to linear length of stream channels in a drainage rather than stream surface area. Small streams therefore account for most of the available habitat for juvenile anadromous cutthroat trout in typical coastal drainages, where high rainfall results in a significant proportion of permanently wetted first or second order streams. For example, fish-bearing streams less than 1.5 m bankfull width (S4) contributed to 16% of total stream length and an estimated 11% of the juvenile cutthroat trout population at summer low-flow in Meares Creek, a representative third-order coastal drainage (Chapter 2). Channels less than 2 m width represented 43% of linear channel length and 39% of the estimated juvenile trout population in the same stream. The potential contribution of small streams to winter habitat is proportionally greater, since streams less than 1.5 m width contributed to 23-57%

of total wetted channel length in low gradient drainages surveyed during winter high discharge (Chapter 2).

In summary, juvenile cutthroat are most likely to be present in smaller low gradient streams, and populations are likely to be largest in drainage basins and landscapes with abundant small low-gradient S3 and S4 tributaries.

Habitat requirements of adult cutthroat are poorly understood, but it is generally thought that adults forage in nearshore areas rather than in the open ocean , and are most abundant in streams and rivers with extensive estuarine habitat (Trotter 1997).

Instream requirements

Juvenile summer rearing

Within a stream channel, the highest densities of yoy fish occur in shallow riffle and run habitats, and the lowest densities are in pools. In contrast, the highest densities of older larger parr are in pools and deeper habitat (Chapter 1). Habitat selection experiments demonstrate that yoy prefer pools despite occurring at highest densities in shallow habitats (Chapter 3). Growth rate experiments indicate that pools are required habitat for growth of older cutthroat trout during summer baseflow, and preferred habitat for yoy fish, which can grow in both pools and riffles (Chapter 3). Juvenile abundance in sand-gravel-cobble streams is likely limited by abundance of pools and LWD, since older juvenile trout require pools for growth at baseflow, and the abundance of older trout is highly correlated with both pool and LWD abundance (Chapter 2).

Overwintering

Overwinter mortality of juveniles may be a bottleneck for many salmonid populations (Tschaplinksi and Hartman 1983; Heifetz et al. 1986; Roberge 2000). Winter is a time of high mortality associated with floods, lower water temperatures, reduced metabolism, and possibly decreased food availability. Juvenile coho typically seek habitats that are sheltered from high flows during the winter, occurring at their highest densities in off-channel habitats (e.g. sloughs) or habitat types with low current velocities such as beaver ponds or sheltered backwater pools (Nickleson et al. 1992). Preferred mainstem habitats when off-channel habitats are not available tend to be deep pools associated with logs (Tschaplinski and Hartman 1983) or root wads (Bustard and Narver 1976; Heifetz et al.

1986). Experiments with juvenile coho salmon in artificial stream channels demonstrated that coho only remained in channels at high flow if LWD and velocity refuges associated with channel complexity were present (McMahon and Hartman 1989). Surveys contrasting densities of juvenile salmonids in streams that were clearcut logged vs. streams with riparian buffers or old growth also found that fish densities were lowest in clearcut streams with low channel complexity and highest in complex reaches with abundant LWD, primarily in old growth or buffered streams (Murphy et al. 1986). Direct measurement of juvenile coho overwinter survival in a Washington stream also demonstrated that overwinter survival was strongly correlated with reach complexity and abundance of LWD (Quinn and Peterson 1996). This body of research supports a general paradigm that LWD and associated channel complexity are critical habitat features for creating winter velocity refuges for overwintering juvenile salmonids.

Although most of the studies described above pertain to juvenile coho, coho co-occur with juvenile cutthroat trout in many streams (Rosenfeld et al. 2000) and likely have similar overwintering habitat needs. Murphy et al. (1986) found that combined overwinter densities of cutthroat and steelhead parr were significantly lower in clearcut streams and higher more complex at old growth sites, indicating that the ecological generality of the importance of channel complexity and LWD as overwintering habitat applies to cutthroat trout as well. This is further supported by a recent study (Roni and Quinn 2001) that found a significant increase in winter densities of juvenile cutthroat trout following placement of LWD in coastal Washington and Oregon streams.

Small tributary streams have also been identified as important overwintering habitat for both juvenile coho and cutthroat trout (Tschaplinski and Hartman 1983; Hartman and Brown 1987; Brown and Hartman 1988). Coho, cutthroat trout, and steelhead move into minor tributaries during the fall when mainstem discharge increases during spates. Streams used for overwintering include floodplain tributaries as short as 150m and streams that are seasonally dry or intermittent during the summer (Hartman and Brown 1987). Although juveniles were observed to move primarily into floodplain tributaries, it is also likely that trout move upstream into smaller headwater tributaries to overwinter if the stream gradient is sufficiently low.

Spawning

Like all salmonids, cutthroat trout require clean gravel for spawning with interstices that are not filled with fine sediment (Bjorn and Reiser 1991). Salmonid eggs deposited in gravel require an adequate flow of interstitial water to supply oxygen to the embryo, and egg mortality will be high if substrate interstices become filled with sediment (Chapman 1988). Land management practices that lead to substantial sediment inputs will likely reduce both the availabilty of suitable spawning substrate and egg to fry survival, as well as reduce production of aquatic invertebrates through loss of substrate interstices (Newcombe and McDonald 1991). These effects are well-established, and consequently a recognized priority for most stream management activities is to minimize sediment inputs.

Implication for forestry impacts

Forestry activities can have both positive and negative effects on freshwater systems (see reviews in Meehan 1991 or Porter et al. 2000). Negative impacts associated with poor forestry practices include decreased bank stability leading to channel widening and increased sediment inputs, infilling of pools and substrate interstices by fines, decreased LWD recruitment to the stream channel due to removal of riparian forest, increased peak flows (Jones and Grant 1996) leading to decreased channel stability, decreased pool abundance from reduced LWD inputs, and displacement of LWD by scouring flows. In contrast, if stream productivity (e.g. algal growth) is limited by sunlight, then canopy removal following clearcutting may result in increased invertebrate and fish production (Murphy et al. 1981). However, if logging results in loss of pool habitat and a reduction in LWD availabilty and associated overwintering habitat, overwinter mortality may offset any increase in summer growth (Murphy et al. 1986). Even if net productivity increases following logging it is usually transient, persisting for approximately 5-20 years until the riparian zone revegetates and the forest canopy closes (Murphy and Hall 1981; Murphy 1995). Negative impacts typically persist much longer. LWD recruitment models show that clearcutting to the streambank results in decreased abundance of instream wood that may persist for 150 years (Murphy and Koski 1989), resulting in greatly reduced channel complexity and pool abundance. Large inputs of sediment may take decades to flush from a stream or river basin, and decreased channel stability from sediment inputs and increased peak flows may be permanent or require decades of riparian forest succession to stabilize.

Riparian regulations are intended to minimize negative impacts on stream habitat and maintain proper functioning of riparian ecosystems. We consider the specific regulations of the B.C. Forest Practices Code (henceforth FPC) below, in the context of cutthroat trout habitat requirements and the effectiveness of regulations in protecting cutthroat habitat.

Evaluation of B.C. Forest Practices Code riparian regulations

Land-use effects on streams can be divided into two categories: those that impact riparian zones, and those that affect the broader drainage basin outside of the riparian zone, such as road construction and upslope logging. Impacts in the riparian zone directly affect bank stability, sediment and LWD inputs, and stream shading, whereas land-use effects across the entire basin directly influence the timing and magnitude of peak discharge (Jones and Grant 1996), which may indirectly influence instream channel structure.

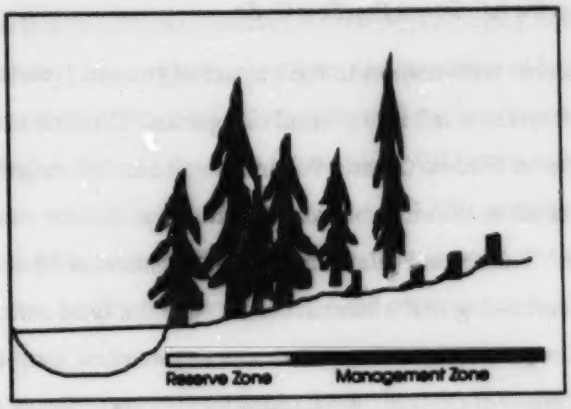


Figure 15. Schematic illustrating riparian reserve and management zones adjacent to the stream channel. Timber harvest is permitted in the Riparian Management Zone but not in the Reserve Zone. Width of Reserve and Management zones are a function of bankfull channel width (see Table 6).

Riparian regulations

The FPC designates reserve zones on all fish-bearing streams greater than 1.5 m bankfull channel width (Table 6, Fig. 15). There is no riparian reserve zone on fish-bearing streams less that 1.5 m channel width (S4) or fishless streams (S5 and S6). Forest harvest is not permitted in reserve zones. Riparian management zones are adjacent to reserve zones. Width of both riparian reserve and management zones depends on stream class. Timber harvest is permitted in riparian management zones, including

clearcutting as well as variable or complete retention at the discretion of forestry planners.

Riparian Class	Average Channel Width (m)	Reserve Zone Width (m)	Management Zone Width (m)	Total Riparian Management Area Width (m)
S1 large rivers	≥ 100	0	100	100
S1 (except large rivers)	> 20	50	20	70
S2	> 5 ≤ 20	30	20	50
S3	≥ 1.5 ≤ 5	20	20	40
S4	< 1.5	0	30	30
S5 (FISHLESS)	> 3	0	30	30
S6 (FISHLESS)	≤ 3	0	20	20

Table 6. Width of riparian reserve and management zones for the different classes of stream channel defined under the B.C. Forest Practices Code.

Specific concerns with respect to the impact of current riparian regulations on small cutthroat trout streams fall into several categories. The first is the absence of a riparian reserve zone on fishless (S5 and S6) and small fish-bearing (S4) streams, which are frequently harvested to the streambank, and the potential for cumulative effects on downstream reaches. The second relates to misclassification of S3 streams as S4, which usually results in clearcutting to the stream bank. And the final concern is with enforcement of FPC regulations, and the absence of systematic long-term monitoring to evaluate the effectiveness of riparian regulations in the protection of fish habitat. These are considered in more detail below.

Adequacy of reserve zones and best management practices on S4 streams

The FPC designates riparian reserve zones on all fish-bearing streams greater than 1.5 m width, with the exception of very large rivers (British Columbia Ministry of Forests 1995). Reserve zones serve several functions: they maintain shading of the stream preventing excessive warming, maintain bank stability, prevent sediment inputs, and ensure that there will be a future supply of LWD to the stream that will contribute to pool formation and maintenance of channel structure.

Reserve zones vary under the FPC depending on stream size (indexed by channel bankfull width) and the presence or absence of fish (Table 6). Of particular importance to cutthroat trout are reserve zones on the smaller fish-bearing streams, those less than 5 m bankfull channel width (S3 and S4 streams). S4 streams (fish-bearing

streams less than 1.5 m channel width) have no riparian reserve zone under the FPC, and a 30 m riparian management zone where timber harvest is permitted. The FPC specifies a maximum basal area tree retention of 25% (i.e. 75% of total tree basal area must be harvested) in riparian zones of S4 streams within a forest development plan area (British Columbia Ministry of Forests 1995), so that most of the riparian zones on S4 streams are clearcut.

Removing most of the riparian trees on S4 streams has the potential for cumulative effects on stream habitat. Habitat surveys indicate that 19-84% of pool formation in the limited number of S4 streams surveyed was due to scour associated with LWD (Chapter 1, Fig. 6). For these streams, absence of a riparian reserve zone may lead to a long-term decline in LWD in the stream channel (Murphy and Koski 1989). Although LWD appears to play a significant role in the structure of lower gradient S4 streams with sand-gravel substrate, LWD likely plays a less important role in steeper cobble-boulder S4 streams. However, pools formed by LWD store substantial quantities of sediment and organic matter (Bilby 1981; Smock et al. 1989), and the cumulative implications of LWD depletion in smaller streams for the storage and export of sediment, organic matter, and invertebrates (fish-food organisms) to lower stream reaches are unclear.

Given that S4 streams receive relatively limited protection under the FPC, their importance to anadromous cutthroat trout needs to be carefully considered. S4 streams contributed to 16% of total stream length and an estimated 11% of the juvenile cutthroat trout population at summer low-flow in Meares Creek (see Chapter 2). The potential contribution of S4 streams to winter habitat is proportionally greater, since streams less than 1.5 m width contributed to 23-57% of total wetted channel length in low gradient drainages surveyed during winter high discharge (Chapter 2). Given that S4 streams appear to contribute significantly to both summer rearing and overwintering habitat for juvenile cutthroat and coho, riparian practices that degrade S4 streams will have negative impacts on juvenile cutthroat populations. Insofar as permanently wetted S4 streams contribute to both summer rearing and overwintering habitat, their protection should be given priority within the subset of S4 streams.

Because not all S4 streams are dependent on LWD for channel structure, management guidelines that are non-discretionary (i.e. mandatory reserve zones where

cutting is not permitted as with S2 and S3 streams) tend to be conservative. However, current S4 guidelines ("best management practices") are primarily discretionary, meaning they can be applied where deemed appropriate by the forestry planner or logging crews, which can result in damage to S4 streams either through ignorance or negligence.

Best management practices in S4 streams recommend falling and yarding of timber away from the stream. However, best management practices are discretionary under the FPC, and one recent audit of forest practices (Sierra Legal Defence Fund 1997) found that 53% of S4 streams had some form of cross-stream yarding. (Cross-stream yarding does not necessarily damage stream habitat if the stream is bedrock/boulder controlled, or if elevated yarding prevents contact of the tree with the stream banks; direct yarding of trees across an alluvial stream channel, however, will cause serious bank erosion and deposition of sediment and debris in the stream channel.) It was also found that basal area retention in S4 riparian zones was close to 25%, as recommended by the code. Primary concerns of S4 riparian management relate to bank stability, sediment inputs, and excessive temperatures in temperature-sensitive streams. Because low gradient S4 streams rarely experience extremely high discharge, they may lack the power to transport excessive sediment and debris deposited by cross-stream yarding of felled trees. Although reduction of LWD inputs may have detrimental long-term effects on S4 channel structure, cross-stream yarding of fallen logs can be immediately damaging, causing excessive bank damage and the deposition of sediment and logging debris in S4 channels, and should only be practiced when it will not impact stream channel structure.

Adequacy of reserve zones on S3 streams

Unlike S4 streams, S3 streams (1.5 – 5 m channel width with fish present) have a 20 m riparian reserve zone on either stream bank where timber harvest is not permitted. 20 m riparian reserve zones on S3 streams are generally adequate to protect streams from excessive bank erosion, sediment inputs, and solar radiation (excepting excessive windthrow), but will not necessarily ensure natural levels of recruitment of LWD to the stream channel. This is particularly relevant to cutthroat trout, since LWD is the primary

pool-forming agent in cutthroat streams (Fig. 6), and pools are a requirement for growth of larger juvenile cutthroat at baseflow (Chapter 3) and are important overwintering habitat.

Research by Murphy and Koski (1989) showed that 95% of LWD originated from within 20 m of the stream bank and 100% of the LWD originated from within 30 m in spruce-hemlock forest on the Alaskan panhandle between Ketchikan and Juneau. This study and others formed the scientific basis for designation of a 30 m riparian reserve zone on Alaskan streams in 1988 (Murphy 1995). However, studies in Washington and Oregon (McDade et al. 1990) found that fully 25% of LWD recruitment in first to third order streams originated from distances greater than 20 m from the stream bank. This is attributable to more favourable site conditions that result in taller riparian trees in southern coastal forests, where LWD can recruit from as far as 60 m from the stream bank (McDade et al. 1990). No research has been done on recruitment distances of LWD in coastal British Columbia, but recruitment distances in southern coastal British Columbia are likely similar to those documented by McDade et al. (1990) for Washington and Oregon (75% from within 20 m), and recruitment distances probably decrease along the north coast towards Alaska as maximum potential riparian tree height (determined by site growth potential) decreases. It is also likely that the estimate of 25% recruitment from beyond 20 m is conservative, since the recruitment rates of McDade et al. (1990) were based on number of pieces of LWD rather than volume. More recent research on LWD recruitment in the Oregon Cascades indicates that 20% of the volume of LWD recruits from greater than 50 m from the stream channel in second and third order streams (May and Gresswell 2000). This reflects the larger size of trees slightly removed from the stream bank, and the greater diameter of wood that they contribute to the stream channel. Since large diameter wood is more effective in creating pool habitat, volume of wood probably serves as a better index of the natural rates of LWD input required to maintain channel structure than number of pieces, and further indicates that natural rates of LWD recruitment will not be supported by 20 m buffers at coastal sites with high riparian growth potential.

If pool formation is proportional to LWD abundance in coastal streams, as has been documented in previous studies (Montgomery et al. 1995), then a 25% decrease in the natural rate of LWD input associated with a 20 m buffer width can be expected to reduce the average frequency of pools (and therefore cutthroat habitat capacity) by a similar degree. While 20m riparian reserve zones on S3 streams can be expected to be reasonably

effective in preventing bank erosion (but see consideration of windthrow below), excessive thermal warming, and sedimentation, they are likely to result in a significant (20-25%) reduction of LWD inputs relative to old growth conditions in south coastal streams. In recognition of the need for wider buffers to ensure pre-logging LWD inputs, riparian reserve zones on anadromous streams on federal land in U.S. jurisdictions (including Alaska, Washington, and Oregon) are a minimum 90 m (Murphy 1995).

Trees exposed at the edge of a clearcut are prone to windthrow because they have lost the protection of adjacent forest. In extreme cases, entire 20 m wide buffers can blow down. This will compromise shading of the stream, and may in some instances lead to bank instability and sediment inputs if many trees adjacent to the stream bank have uprooted. Best management practices in the code recommend that sufficient trees be left in the riparian management zone to protect the reserve zone when potential for windthrow is high. Windthrow causes LWD inputs to become episodic rather than continuous over time. However, windthrow is not in itself a major problem from a standpoint of LWD inputs, since trees that have fallen over the stream will eventually enter the channel as LWD and contribute to habitat structure. In general, wider buffer strips are more likely to be windfirm.

Potential for misclassification of S3 streams

Misclassification of S3 streams is a serious concern because it may result in erroneous designation as S4 with no reserve zone, resulting in clearcutting to the streambank.

Classification of streams under the FPC is based on channel width. Because channels consist of many types of habitat units (pools, riffles, runs, glides) that vary in width, a single measurement may not accurately represent average channel width. Average channel width for classification purposes is therefore based on 5 measurements of channel bankfull width spaced approximately one channel width apart (Province of British Columbia 1996). It is critical that inventory crews take unbiased measurements of channel width. Systematic measurement of channel width in narrow channel sections such as riffles will result in underestimation of channel size, and potential misclassification of smaller S3 channels as S4 with no riparian reserve zone. This is a significant concern, as fully 28% of the linear anadromous channel length in Meares

Creek was between 1.5 and 2 m channel width (Chapter 2), and therefor subject to misclassification and minimal riparian protection. Additionally, field inventories of streams in cut blocks need to be extremely thorough, as a large proportion of cutthroat streams are missing on 1:20,000 Terrain Resource Inventory Maps (Chapter 2).

Two independent audits of compliance with the FPC riparian regulations found that the most significant shortcoming was misclassification of streams. The Sierra Legal Defence Fund field audit (1997) found that 11% of stream reaches were not identified on logging plans, and that 29% of stream reaches were misclassified. The Forest Practices Board audit (1998) confirmed this, and found that 52% of S3 channels (fish-bearing streams requiring a 20 m reserve zone) were underclassified as S4 streams (requiring no reserve zone), and most of these misclassified S3 streams were subsequently clearcut to the stream bank. Forty-three percent of fish-bearing S4 streams were misclassified as S6 (fishless) streams, but the direct consequences were less severe since neither S4 nor S6 streams have riparian reserve zones. In 87% of stream misclassifications the error resulted in a lower level of habitat protection.

Misclassification of small streams, particularly S3s, has a major impact on cutthroat trout habitat, since these are the streams where juvenile anadromous cutthroat rear at their highest densities, and where LWD plays a substantial role in channel structure. Misclassification of S3s as S4s results in clearcutting of the riparian reserve zone, and even if bank destabilization and sediment or debris inputs do not immediately result, future recruitment of LWD will be diminished, likely leading to long-term degradation of fish habitat.

S5 and S6 streams and continuity of stream habitats

S5 and S6 streams (fishless streams with channel width of > 3 m and < 3 m, respectively) have no riparian reserve zone under the FPC. The FPC specifies a maximum basal area tree retention of 25% for S5 streams and 5% for S6 streams within a forest development plan area. Concerns with respect to harvesting riparian zones of fishless streams primarily relate to downstream impacts on fish-bearing reaches. Because stream habitats are connected, protection of downstream reaches is dependent on proper management of upstream reaches which are often fishless. As with S4 riparian regulations, application of "best management practices" on fishless streams is

discretionary. Primary concerns are sediment inputs and changes in organic matter storage and export to lower fish-bearing reaches if upstream riparian management compromises bank stability and channel structure of fishless streams.

The ceilings on basal area retention of trees on S4, S5 and S6 streams (25%, 25% and 5%, respectively) are apparently arbitrary with no clear scientific basis, and may constrain the appropriate management of smaller streams. To quote the Riparian Management Area Guidebook (British Columbia Ministry of Forests 1995, Pg. 31), "these recommended forest practices were developed with consideration given to their potential impact on timber supply". When S4 or fishless streams above fish-bearing reaches are alluvial and therefore dependent on riparian forest for stabilizing stream banks and maintaining channel structure, complete removal of riparian forest and inappropriate cross-stream yarding may destabilize stream banks and result in sediment transport to downstream fish-bearing reaches. If channels are bedrock constrained or otherwise non-alluvial, then clearcutting to the stream bank may have much less effect on channel structure and the delivery of sediments to downstream reaches. It is unclear whether the relative proportions of alluvial vs. bedrock control fishless stream channels is such that protection of alluvial channels can be accommodated within the 25% and 5% ceilings on basal retention for S5 and S6 streams. Fishless streams may also in some instances be an important source of LWD to lower fish-bearing reaches, with LWD originating either from the riparian zone, headwater gullies, or hillslopes.

The role of LWD in the storage of sediment and organic matter dynamics in steeper fishless streams in British Columbia is not well understood. Previous research has demonstrated that LWD stores substantial quantities of organic matter and associated invertebrates (fish-food organisms; Bilby 1981; Smock et al. 1989). Removal of log steps may also accelerate mobilization and downstream transport of sediment from the stream channel (Heede 1985), and recent research in small steep stream channels indicates that LWD in steep streams in eastern Washington (Cheaney 2000) and coastal Alaska (Gomi 2000) may store appreciable quantities of sediment and organic matter. There may be cumulative effects of riparian forest removal on S5 and S6 streams that impact downstream reaches, but are poorly documented. Impacts on invertebrate (fish-food) production based on headwater organic matter accumulations and export rates to

downstream fish-bearing reaches are particularly poorly understood, and may be significant.

Authors of the Forest Practices Board audit (1998) indicate that application of best management practices on S5 and S6 streams appear to be largely adequate to protect channel integrity. However, they do note that more systematic long-term monitoring would be desirable to track the longer-term effects of forest practices on windthrow and long-term channel stability. It should also be noted that riparian regulations on federal land in the Pacific Northwest United States require minimum no-harvest zones of 46 m (Murphy 1995) on perennial fishless streams (equivalent to S5) and 30 m on intermittent fishless streams (equivalent to S6), indicating a recognition that intact riparian buffers are necessary to fully protect overall riparian ecosystem function. Designation of wider buffers also reflects the fact that riparian zones are critical habitat for wildlife other than fish, including amphibians (Corn and Bury 1989), birds (Wiebe and Martin 1998), or mammals that require intact riparian zones as resident habitat or as corridors for movement and dispersal.

Monitoring and enforcement of FPC regulations

Monitoring and enforcement is an administrative rather than a technical aspect of the code. It is not specific to cutthroat trout, but nevertheless has far-reaching implications for the effectiveness of habitat protection. The preceding analysis of FPC regulations is predicated on the assumption of full compliance with FPC regulations. Significant shortcomings in the application or enforcement of FPC regulations may cause habitat protection to default to a lower level and render the actual details of FPC regulations irrelevant.

Two recent independent audits (Sierra Legal Defence Fund 1997; Forest Practices Board 1998) have been conducted to assess operational compliance with FPC riparian regulations and their effectiveness in protecting coastal stream habitat. The audit by the Sierra Legal Defence Fund (1997) observed that 36% of streams (primarily S4s, S5s, and S6s) were cross-stream yarded and 17% had prescriptions of yard away "where possible", which was interpreted as potentially damaging to stream habitat. However, this was not necessarily non-compliance, since the observed retention of riparian forest in management zones was close to that recommended by the code, although the long-term effects of this level of retention is subject to debate. The Forest

Practices Board audit found relatively high levels of compliance (an average 88% consistency between field operations and recommended prescriptions in logging plans), which included some degree of cross-stream yarding on 54% of non-fish streams. However, the Forest Practices Board audit concluded that riparian management prescriptions resulted in relatively little short-term alteration of stream habitat. Both reports found significant misclassification of stream channels in operational planning, with serious implications for the protection of cutthroat trout habitat as discussed above.

The B.C. Forest Practices Board has identified significant and systematic violations of the FPC with respect to protection of fish habitat in other jurisdictions (Forest Practices Board 1999), where lack of personnel and resources for monitoring and enforcement may be a primary cause. This suggests that monitoring and enforcement rather than technical details of FPC regulations may be the most immediate shortcoming of the FPC for the protection of anadromous cutthroat trout habitat.

RECOMMENDATIONS

1) Permanently wetted S4 streams are used by juvenile cutthroat trout and coho salmon for summer rearing, and some S4 streams are also important as overwintering habitat. Riparian reserves should be maintained on all low-gradient alluvial S4 streams where LWD is likely to play a role in channel structure. Cross-stream yarding of S4 streams should only be permitted when it will not result in damage to the stream, e.g. when it is a bedrock or boulder-controlled (non-alluvial) channel, or if trees can be cabled or otherwise yarded without contacting the stream banks.

2) Underclassification and failure to identify small streams are critical factors leading to degradation of small streams and cutthroat habitat. While the code does afford some protection to smaller S3 cutthroat streams, this protection is negated when streams are misclassified as fishless or S4 and clearcut to the streambank. In addition to failure to identify streams during operational inventory and planning, misclassification is probably the most immediate cause of degradation to cutthroat trout habitat. There is a need for more thorough stream identification in the field, including better training of personnel and quality control on channel width measurements and methodologies.

3) The ceiling on basal area retention on S4, S5 and S6 streams (25%, 25%, and 5%, respectively) should be removed or reviewed, as it has no clear scientific basis and may compromise riparian protection by mandating minimal retention of stream-side forest. Riparian buffers should be retained on fishless streams above fish-bearing reaches and S4 streams when they are alluvial and therefore dependent on riparian forest for stabilizing stream banks and maintaining channel structure. Buffer strips are less of a concern on bedrock controlled or non-alluvial channels unless shading or transport and supply of LWD to lower reaches is a concern.

4) The role that LWD in S4 and fishless (S5 and S6) streams plays in the retention and transport of sediment, organic matter, and fish-food organisms to lower fish-bearing reaches is poorly understood. There is the potential for systematic clear-cutting to the

stream bank to result in cumulative negative effects on downstream fish-bearing reaches. The importance of small streams to metabolic processes in the drainage network and the significance of LWD for storage and production processes requires clarification.

5) Twenty meter riparian reserve zones on S3 streams are generally adequate to protect streams from excessive solar radiation (excepting excessive windthrow), bank erosion, and sediment inputs, but are likely to cause a long term decline in LWD abundance because approximately 25% of LWD recruits from beyond 20 m in south coastal streams. Riparian reserve zones on anadromous streams on federal land in U.S. jurisdictions (including Alaska, Washington, and Oregon) are a minimum 90 m (Murphy 1995), and 30m on state lands in Alaska. Riparian buffers on S3 streams (1.5-5 m channel width) should be extended to a minimum 30 m to maintain riparian ecosystem function (natural rates of LWD input) and prevent long-term degradation of channel structure.

6) Commercial salvage of windthrown riparian trees should not be permitted in alluvial stream channels, since windthrow will eventually enter the stream and contribute to channel structure and fish habitat. Salvage will reduce the long-term recruitment rate of LWD to the stream channel below natural levels. Salvage should only be permitted if it can coincide with careful and deliberate placement of LWD in the stream channel during salvage operations (to ensure "no net loss" of LWD recruitment).

7) A long-term program should be established to monitor and evaluate the effectiveness of FPC best management practices on S4, S5 and S6 streams in maintaining channel structure and reducing sediment inputs to downstream fish-bearing reaches.

8) More resources need to be dedicated to monitoring and evaluating the effectiveness of the FPC in terms of both technical/ecological considerations and enforcement.

9) Because riparian regulations and best management practices in the B.C. Forest Practices Code are largely discretionary, logging operators and planners unfamiliar with the critical importance of small streams may seriously damage fish habitat. Training

programs to educate planners, forestry crews, and machinery operators about the critical importance of small streams and the application of appropriate riparian management practices are essential for the long-term protection of small-stream fish habitat.

CONCLUSION

Large Woody Debris (LWD) from riparian (streamside) trees falling into the stream channel has been shown to be the major pool-forming mechanism in small and medium-sized coastal streams, and pools and the complex habitat associated with LWD are critical habitat for juvenile salmonids. Until the early 1990's, most streams in coastal British Columbia, both large and small, were clearcut to the streambank, resulting in the cessation of inputs of LWD from the riparian zone. The long-term implications for stream habitat structure and productive capacity are quite clear: instream habitat in many small and medium sized streams dependent on LWD for channel structure and complexity will degrade as pre-logging LWD in the stream channel breaks down without replacement. Even for streams not adversely affected by excessive sediment inputs, channel structure and juvenile rearing capacity will continue to decline in the foreseeable future (over the next 50-100 years), and recovery will not occur until riparian forests mature sufficiently for larger trees to begin dying and entering stream channels in significant numbers. While stream restoration and rehabilitation can address some of this habitat loss through placement of logs and other structures in streams (Slaney and Zaldokas 1997), stream rehabilitation is extremely expensive, and the cost of restoring the thousands of kilometers of stream channel that are being adversely affected by reduced LWD inputs is prohibitive. The intent of riparian regulations in the B.C. Forest Practices Code and other riparian protection legislation is to prevent further damage to stream habitats, and ensure that the ecosystem functions provided by intact riparian zones are not compromised by resource extraction or other landuses.

Research described in this report highlights two specific habitat requirements of cutthroat trout that have important implications for habitat management. First, at the drainage basin or landscape scale, anadromous cutthroat trout depend primarily on small (< 5 m channel width) low gradient streams or tributaries to larger rivers for juvenile rearing. Small streams that are permanently wetted are used as summer low-flow rearing habitat, and small seasonally wet streams are used as overwintering habitat. Second, at the instream habitat scale pools are critical habitat, and most pools

are formed by scour associated with LWD unless the channel is steeper gradient and boulder or bedrock controlled.

An evaluation of the B.C. Forest Practices Code riparian regulations and operational procedures with respect to protection of cutthroat habitat identifies several significant shortcomings. While some of the shortcomings of the FPC identified in this report might individually cause limited habitat degradation, the different effects are additive and therefore the potential for significant cumulative impacts exist. This potential is increased by the fact that most of the shortcomings identified relate to the protection of smaller streams which constitute the majority of the stream network.

Independent audits (Sierra Legal Defence Fund 1997, Forest Practices Board 1998) have found the systematic misclassification of streams to be the most immediate short-term operational problem diminishing the effectiveness of riparian protection. A large proportion of small (S3 or S4) streams in cutblocks were found to be unidentified during operational planning or misclassified so that they received a lower level of riparian protection than required under the code. Fifty-one percent of S3 streams were misclassified as S4 in one audit (Forest Practices Board 1998), resulting in the 20 m riparian reserve being clearcut to the stream bank on 35% of the audited S3 streams. This is particularly damaging to anadromous cutthroat trout habitat because juvenile trout rear at their highest densities in S3 and S4 streams, and clearcutting will reduce the future recruitment of LWD inputs to the stream channel, likely resulting in future decreased pool frequency and lowered habitat capacity.

Although the Forest Practices Code does provide protection for many aspects of riparian ecosystem function, it has technical shortcomings that will contribute to cumulative negative impacts on anadromous cutthroat trout rearing habitat. These include reduction of LWD input rates in S3 streams because of inadequate riparian buffer width; degradation of alluvial S4 stream channel structure through long-term depletion of LWD inputs from clearcutting to the stream bank and the negative impacts of inappropriate cross-stream yarding; and potential increased sediment and decreased LWD transport to downstream reaches from fishless S5 and S6 streams. Although the 1998 Forest Practices Board audit of riparian management in coastal BC found reasonably good compliance with FPC riparian management regulations (correct classification of streams excepted), incidents of poor compliance and enforcement have

been found in other regions (Forest Practices Board 1999), indicating a need for enhanced monitoring and enforcement of code regulations. Ensuring effective protection of stream habitat requires the development of formal programs to monitor compliance and evaluate the effectiveness of different riparian management practices. This should include the regular monitoring of treated sites to evaluate the long-term effects of different riparian prescriptions (e.g. windthrow frequency and extent).

This study documents the disproportionately large contribution of small streams to anadromous cutthroat trout and coho salmon rearing habitat in coastal drainages, and highlights the need for riparian regulation and land-use management practices that adequately protect small streams. This is becoming increasingly urgent in British Columbia, as continued urbanization, agriculture, and logging in low-gradient landscapes exerts increasing pressure on small stream habitat and their associated fish stocks (Murphy 1995; Reeves et al. 1997; Healey et al. 1999). There has been recent progress towards management practices that protect larger streams and rivers, embodied by some of the riparian regulations of the Forest Practices Code, but the recognition of the importance of small streams and management actions to protect them are lagging. Small streams are critical rearing habitat for juvenile salmonids in coastal British Columbia, and the connectivity of river systems dictates that small headwater streams cannot be degraded without also compromising the integrity of downstream reaches.

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